GENERAL MOTORS ENGINEERING JOURNAL

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for educators in the fields of engineering and allied sciences

ENGINEERING FOR HIGHWAYS

On Engineering Opportunity

Belief in the importance of change is one of the great traditions which are a part of the rich heritage of America. Our earliest settlers were motivated by the urge for change—spiritual, political, or economic. This spirit of our pioneers propelled them westward, cleared our farm lands, raised our great cities, created new industries and new ways of life for us all. Search for the better method, the better product, seeking to replace the old with the new and improved—this has formed the pattern of our progress.

No industry has contributed more to our nation's growth and development than the automobile industry. Its products have changed completely the face of America and the habits of Americans. No industry has done more to raise the United States to a position of world strength and leadership.

The reason is that the automobile industry, as no other industry, makes a practice of investing regularly and heavily in planned change. We call the process dynamic obsolescence. Each year General Motors invests hundreds of millions of dollars to bring its new models to market. In 1956 alone we spent $915 million for capital improvements. This amount was an increase over similar expenditures of previous years and represents our intention to keep our facilities modern and in step with an expanding economy.

Programs of this scope typify the dynamic atmosphere in which General Motors people work. We have developed an approach to problems which I call the attitude of the inquiring mind. It might be defined as bringing the research point of view to bear on all phases of the business. It assumes that anything and everything can be improved.

The inquiring mind contributes to the progress of technology—and indirectly to the progress of the nation—in each automotive model change and in the continuing developments in our non-automotive products. Such General Motors developments as our automotive fuel injection system, air suspension for buses and trucks, prop-jet engines for commercial airliner use, twin-power tractors and earthmovers, and the unit-kitchen are all the result of our emphasis on the process of accelerating obsolescence. In our laboratories and design rooms, we are concerned both with tomorrow's products and with advance planning for products and processes far into the future.

I stated a year ago my belief that our country is moving toward a gross national product of $550 billion by 1965. This objective may well be a conservative one. It is not, however, one that can be achieved automatically and without constructive planning and hard work.

To provide an industrial structure capable of supporting a gross national product of this size in less than 10 years is the great challenge that lies ahead for all industry. It is a challenge that must be met with new and improved facilities. It is also a challenge in the area of technology because all progress derives in the last analysis from technological progress.

Thus, it is a challenge for the engineer and the scientist. Particularly, it is a challenge for the young men and women in our colleges and high schools who are looking ahead to technical careers and from whose ranks will come tomorrow's leaders in engineering and science.

Finally, it is a challenge for all of those concerned with the processes of education. And that includes teachers and parents, of course, but also those of us who might be called the customers of education—who employ its "products" in our businesses.

The need is great to encourage more young people to study science and mathematics. Perhaps we in industry have not done enough to make clear the wonderful opportunities to which science and mathematics provide the key. I can say in all sincerity, and based on 42 years of experience in General Motors, that I know of no trade or calling or profession that offers more in the way of opportunity for constructive accomplishment, service to one's fellow men, and substantial personal achievement than a career in engineering or science.

Harlow H. Curtice

Harlow H. Curtice
President,
General Motors Corporation

THE COVER

This issue's cover design—by artist John B. Tabb—is another depicting developments in transportation. Symbolically, it suggests application of the fundamentals of highway engineering and mechanical engineering which become partners in the job of building modern roads. One of the necessities in a construction program is a fleet of rugged, powerful earthmoving machines. Engineers are continually improving the design of these machines. For example, new records in earthmoving production are being set by more powerful crawler tractors using 2 engines and by carry-scrapers which also employ the twin power principle with engines fore and aft to provide 4-wheel drive.

Such improvements mean higher construction efficiency in building the nation's system of modern highways, which can be vital in any emergency situation and which also will allow traffic to move with greater safety and convenience.

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Evolution of a Twin Engine, 4-Wheel Drive, Earthmoving Carry-Scraper

By WILLIAM J. ADAMS
and EDWARD R. FRYER
Euclid Division

Earthmoving projects require a variety of equipment, chief of which is the scraper used in land leveling operations for the initial clearing and movement of various free-flowing earth materials. Since the mid 1800s the scraper has developed both in load carrying capacity and mobility. Horses and mules pulled the early-day drag-type scrapers, which had a capacity of 1/3 cu yd and an operating speed of 2 mph. The introduction and subsequent development of the crawler tractor, the automatic closing front apron, and rubber tires capable of supporting heavy loads were significant steps in the evolution of the scraper which, by 1945, had a capacity of 12 cu yd and was pulled at a speed of 15 mph by a tractor having 150 hp. The increased activity in earthmoving projects following World War II required scrapers of greater capacity. A point had been reached, however, where the horsepower and drawbar pull required to move scrapers of increased capacity could not be adequately provided for by the single engine, single drive-axle tractor units then in use. To meet the need for increased engine horsepower and tractive ability, the principle of twin power—2 engines, each driving a separate drive axle—was applied to the carry-scraper. The application of twin power to a self-loading carry-scraper required that Euclid Division engineers solve many problems related to synchronization of the 2 separate power trains, remote control of the rear engine, and hydraulic control of the scraper assembly components. The successful solution to these problems has resulted in today's scraper which has a capacity of 24 cu yd and is pulled along at 30 mph by 2 engines having a total maximum power output of 518 hp.

It took the first 100 years to achieve a capacity which has been doubled in the last 10

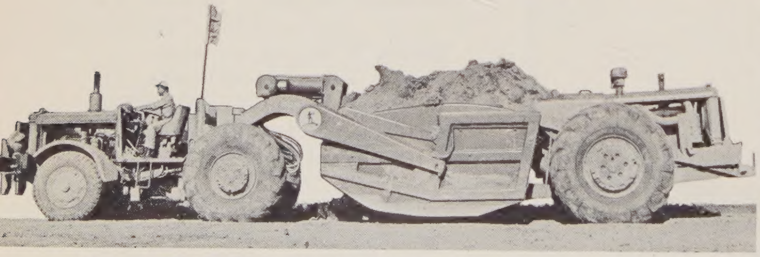
The construction of a highway or dam or the site clearing for a residential housing or industrial plant development requires the movement of thousands of cubic yards of free-flowing materials, such as sand, dry earth, wet clay, shale, and gravel. One type of earthmoving machine which plays a major role in the initial movement of such materials is the scraper which scoops up material from the "cut" and transports it to the "fill."

The period following World War II marked the beginning of increased activity in earthmoving projects. More dirt had to be moved at a volume exeeding that of pre-war years. As a result, earthmoving contractors desired scrapers having increased capacity and a faster hauling speed.

The requirements for a scraper of increased capacity presented problems which could not be solved simply by enlarging the scraper bowl to hold more earth material. This, of course, would satisfy the increased capacity requirements, but attention also had to be given to the problem of meeting the corresponding increase in power necessary to move the scraper unit carrying a greater load.

The average post-war scraper had a capacity of approximately 12 cu yd, or 18 tons, and was pulled at a speed of 15 mph by a 2-wheel or 4-wheel rubber-tired tractor having a 150-hp Diesel engine and a single drive-axle. To obtain better efficiency, earthmoving contractors found that the use of 1 or 2 crawler tractors to push the scraper during a loading operation provided the additional power needed to pack more material into the scraper and also decreased the loading time normally required. This practice, however, not only required the use of additional machines but also raised operating costs.

When Euclid Division engineers first studied the problem of developing a higher capacity scraper, consideration was given to the fact that each cubic yard increase in scraper capacity would add approximately 1½ tons to the load. A capacity increase of 10 cu yd, for example, meant that 15 tons of additional material would have to be moved. To maintain accepted performance standards, more power was required with increased capacity. More power would be needed—not only in the tractor engine but also in the power transmitted through the single drive-axle. The drawbar pull, or useful turning force applied to the driving wheels, would have to be greatly increased to give a scraper, having a suitable increase in capacity, the necessary tractive ability for difficult hauls and steep grades.



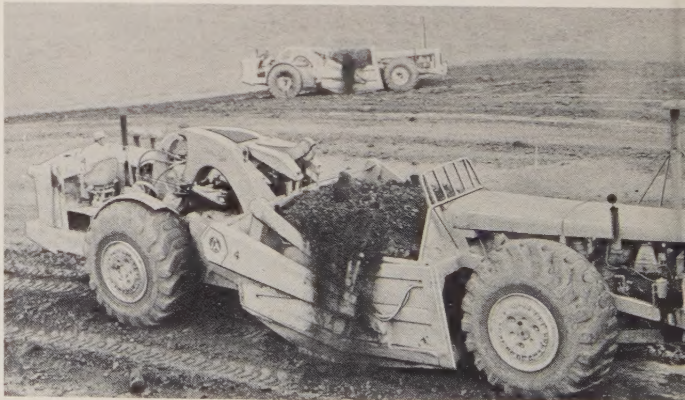


Fig. 1—The design of the 1949 Euclid twin engine, 4-wheel drive, carry-scraper (above) was based on adapting the principle of twin engine power, first used on Euclid dump trucks, to the requirements of a scraper which would self-load, transport, and then spread and grade its load. The present-day Euclid TS-18 twin engine, 4-wheel drive scraper (right) uses the overhung engine principle of design. This allows nearly equal weight distribution on the front and rear wheels whether the scraper is empty or loaded to capacity.

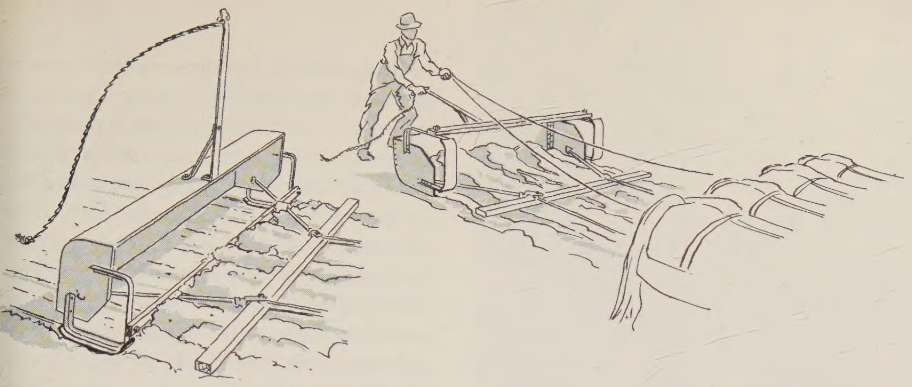


Fig. 2—This sketch illustrates the general design of the Fresno scraper used extensively between 1875 and the early 1920s for all short haul earthmoving. The scraper was controlled by a *Johnson bar* extending from the rear of the bowl. When the scraper was in the dumping position (lower view), the height of the bar made it necessary for the operator to use the rope to pull the scraper back to the loading position.

The major problem, therefore, became one of finding an efficient and economical method of providing the required power increase to both the engine and driving wheels. Previously, Euclid engineers faced a somewhat similar problem regarding power increase requirements for the line of 34-ton and 50-ton rear-dump trucks. The solution to this problem was found by applying the principle of twin power —2 engines mounted side by side each driving a separate drive axle. The question was asked, "Why not apply this principle to the development of a scraper of increased capacity?" The use of 2 engines would provide the required horsepower. The 2 drive axles would provide 4-wheel drive to utilize effectively the available engine horsepower. Tractive ability, or drawbar pull, is dependent upon tire weight times friction coefficient; therefore, the more wheels powered, the more drawbar pull available. Also, the application would have economic advantages in that relatively high production, low cost engines, transmissions, and axles, which were already in use on the smaller machines, could be used.

Preliminary studies indicated that such a twin-engine scraper was feasible, and a full-scale developmental program was inaugurated. For the scraper application, however, the twin power principle, as originally used on Euclid trucks, would be modified by having 1 engine mounted forward of and 1 engine behind the scraper unit to provide a push-pull effect. The developmental program reached a successful conclusion in 1949 when Euclid introduced its first twin engine, 4-wheel drive, self-loading, carry-scraper (Fig. 1a). This scraper, having a struck capacity of 18 cu yd, performed the multiple operations of scooping up earth loads of between 25 tons and 35 tons, transporting and then discharging the load at the dump or earth fill, and, finally, leveling and grading the entire project, including the cut, the fill, and the haul road. The unit was powered by 2, 190-hp Diesel engines.

The field experience gained from the first twin engine scraper was applied to further development and improvement of the original design. In 1955 the Euclid TS-18, 4-wheel drive, carry-scraper (Fig. 1b) was introduced. This scraper, in use today, has an overhung engine design, provides a heaped load capacity of 24 cu yd, is powered by 2, 218-hp Diesel engines (or 1, 300-hp and 1, 218-hp Diesel engine), and has a hauling speed of 30 mph.

Although the TS-18 scraper is called a twin because of its fore and aft power plants, the all-wheel drive method is the fundamental factor accounting for the performance and increased production output. In addition to the greater traction for loading, the higher power-to-weight ratio of the TS-18 scraper provides faster acceleration and better ability to negotiate grades or overcome a high rolling resistance. Another feature, generally not recognized, is the added maneuverability which results from the fact that drive from the rear engine helps the steering and the pivoting of the tractor with respect to the scraper.

The Euclid TS-18 carry-scraper represents the latest step in the evolution of the western land-leveling and grading type of earthmoving scraper. This evolution has been based on the application of basic engineering fundamentals plus practical experience relating to scraper operations gained through the years. It is of interest, therefore, to review some of the past history and evolution of scraping techniques.

Scraper Evolution Parallels Growth of America

When the early settlers reached the western United States in the mid 1800s, they were faced with the task of leveling land for irrigation to make it more suitable for farming and the construction of roadways and irrigation canals and ditches. From this need came the basic form of the western land leveling and grading type of scraper which, in general, dumps the earth load forward of its cutting edge and uses the cutting edge as a grading member to spread and level the dumped load.

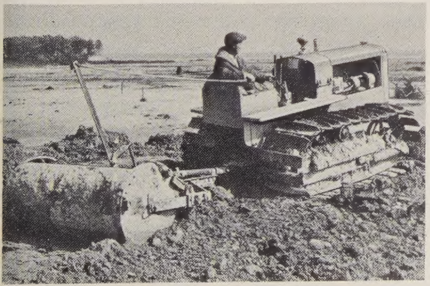


Fig. 3—This track-type, tractor-drawn Euclid scraper, first built in 1925 and known as the "tumblebug," allowed the operator on the tractor to control the cut and dumping operations by a "jerk line" control of the lever mounted at the center of the scraper.

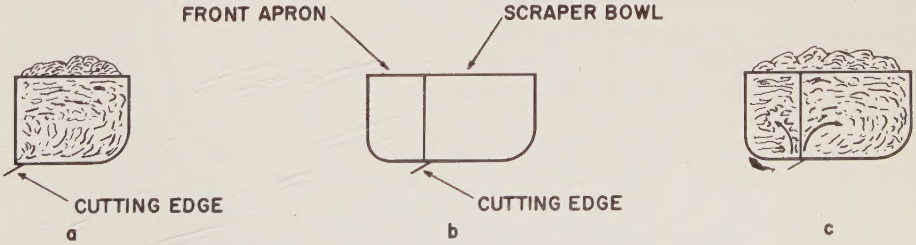


Fig. 4—The development of the automatic-closing front apron in the mid-1920s marked a significant advancement in scraper evolution. Prior to its development, the scraper bowl was somewhat of a rectangular box (*a*) in which the cutting edge was placed at the forward end. The load-carrying front apron represented an extension to the forward end of the scraper and permitted the cut to be scooped up near the center of the bowl (*b*). This allowed the cut to enter into both the apron and the scraper bowl (*c*) which resulted in larger capacity heaped loads.

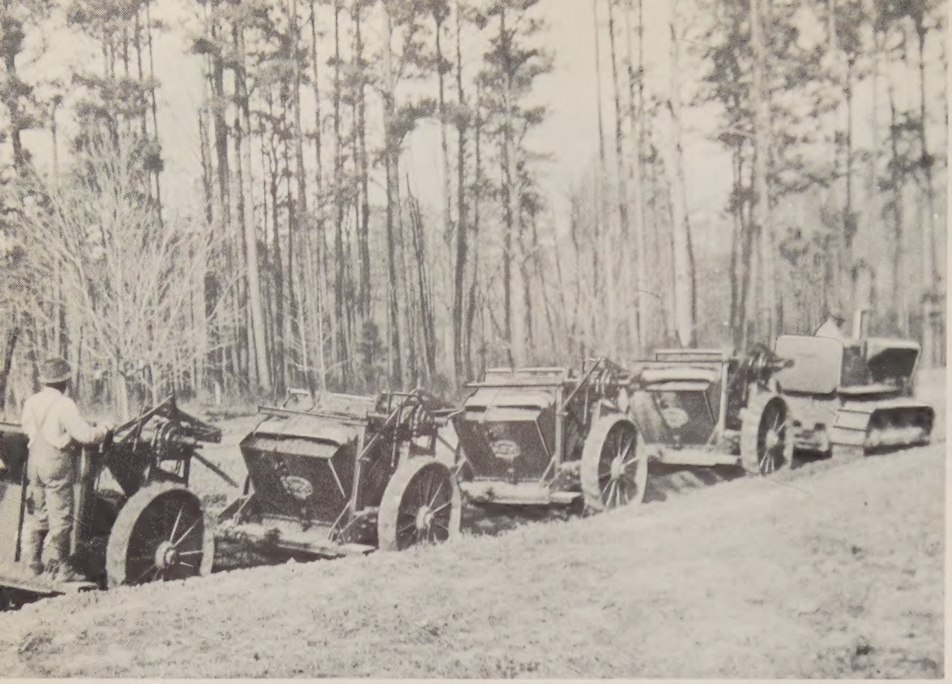


Fig. 5—These Euclid steel wheel scrapers, combined to form a "train," were used between 1925 and 1936. The operator standing on the rear scraper was kept busy running from unit to unit to load and unload them. The scrapers were made in 1-cu yd and 1½-cu yd capacities.

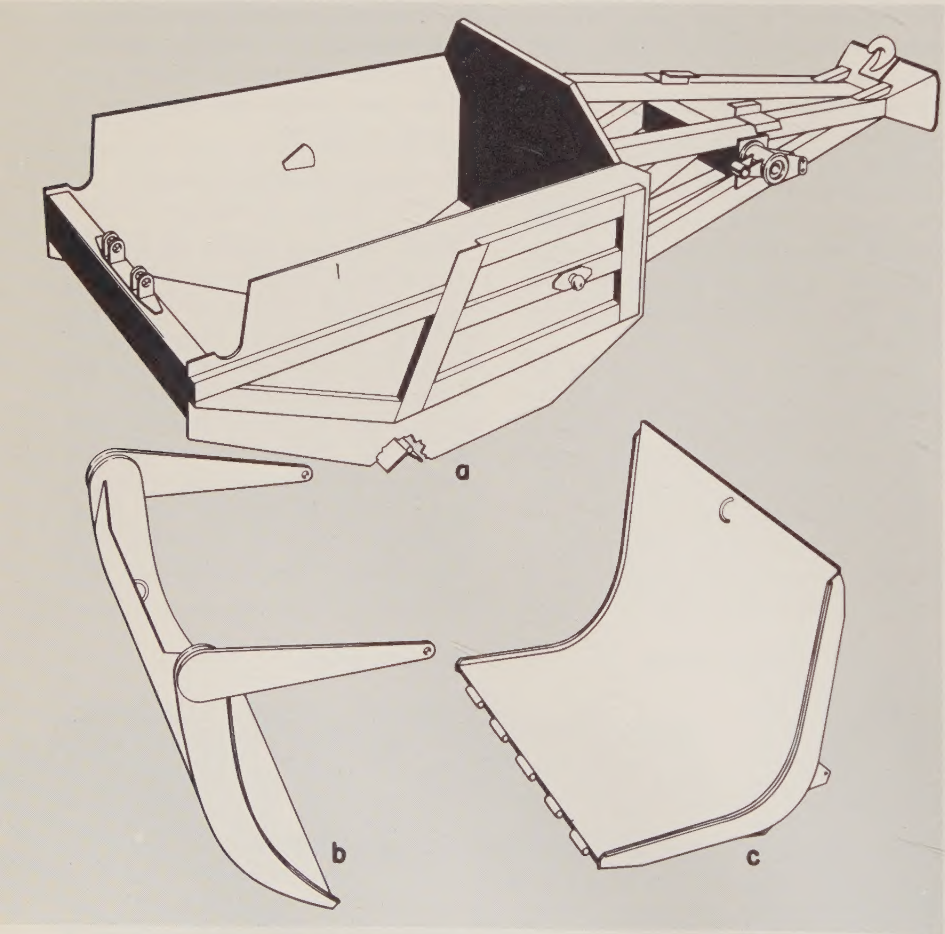


Fig. 6—The major components of the scraper assembly are the scraper bowl (*a*), the apron (*b*), and the ejector (*c*). The apron is mounted inside the forward end of the bowl by means of arms which are pinned to the side members of the bowl. The pins act as pivot points for the apron as it performs its function of varying the scraper bowl opening during a loading or ejecting operation. The ejector acts as the rear portion of the bowl and is hinged to the bowl at the cutting blade base.

The practical forerunner of the western type of earthmoving scraper was the Mormon buckboard, developed by the early Mormon settlers to level land and build ditches and canals necessary for irrigation of the Utah desert soils. The Mormon buckboard was a wooden board having a strip of iron for a cutting blade attached to its bottom front edge. The unit was mule or horse drawn, and the operator controlled the scraper by a handle extending from the rear of the board.

The next development in scraper evolution—an adaptation of the Mormon buckboard—took place in Fresno County, California. The Fresno scraper (Fig. 2) was a curved steel-bowl, horse drawn, drag-type scraper having end pieces to hold more dirt and a wide, flat cutting edge which allowed for easy dragging of the earth load from the cut to the fill. End runner shoes and a simple, adjustable "dump bar" permitted fairly accurate grading control of dumped earth loads. Fresno scrapers became world famous and between 1875 and the early 1920s were used extensively for all short haul earthmoving connected with land leveling, canal and levee building, road and highway construction, and railroad grading.

During the early 1920s, the crawler tractor and the steel wheel farm tractor became dependable and practical operating machines and signaled the end of horse drawn, low-capacity scrapers. Larger capacity drag-type and also part-drag and part-carry scrapers were built to be pulled by tractors. In 1925 Euclid built a tractor drawn roll-over or "tumblebug" version of the Fresno scraper (Fig. 3) which had capacities ranging from 18 cu ft to 56 cu ft.

During this period a very significant contribution to scraper evolution took place with the development of a curved, earth carrying, automatic closing front apron (Fig. 4). The load carrying front apron represented an extension to the length of a scraper bowl and permitted the earth cut to be scooped up near the center of the bowl. This was a marked difference in scraper operation as the cut had been previously scooped up at the front end of the scraper bowl.

With the use of the front apron a portion of the cut was first rolled forward on and then into the front apron. The balance of the cut was forced back on and then into the scraper bowl. In this manner the front apron and scraper bowl loads were combined into larger capacity, heaped earth loads.

The front apron made it possible to scoop up and carry, instead of drag, both wet and dry types of earth soils. The development of the front apron not only allowed the building of larger capacity scrapers but permitted full scraper loads to be lifted clear of the ground and transported on wheels. This brought into being the carry-scraper and eliminated drag-type and part-carry scrapers.

Between 1926 and 1936 Euclid built a crawler tractor drawn, steel wheel carry-scraper available in a capacity of either 1 cu yd or 1½ cu yd. To increase the overall amount of earth moved, individual wheel scrapers were combined into "trains" (Fig. 5).

The introduction, in the late 1930s, of low-pressure rubber tires capable of supporting heavy loads signified another important step in scraper evolution. The rubber tires served to increase the haul range and general utility of the carry-scraper. They also permitted an increase in the amount of scraper yardage production and allowed for faster and lower-cost scraper earthmoving.

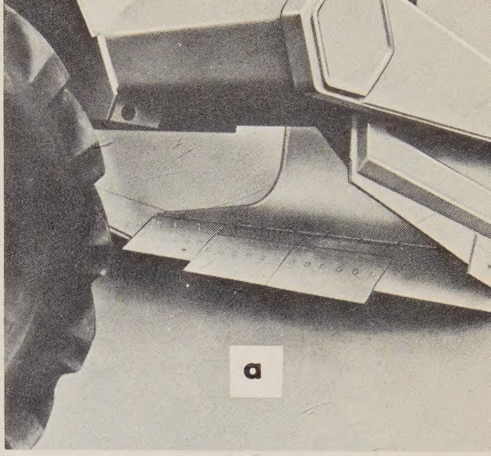
Between 1932 and the end of World War II, increases in scraper capacity were coupled with horsepower increases in the Diesel engines used to power crawler tractors. Also, the power control unit was perfected whereby power from the tractor engine was utilized to actuate the scraper during its work cycle.

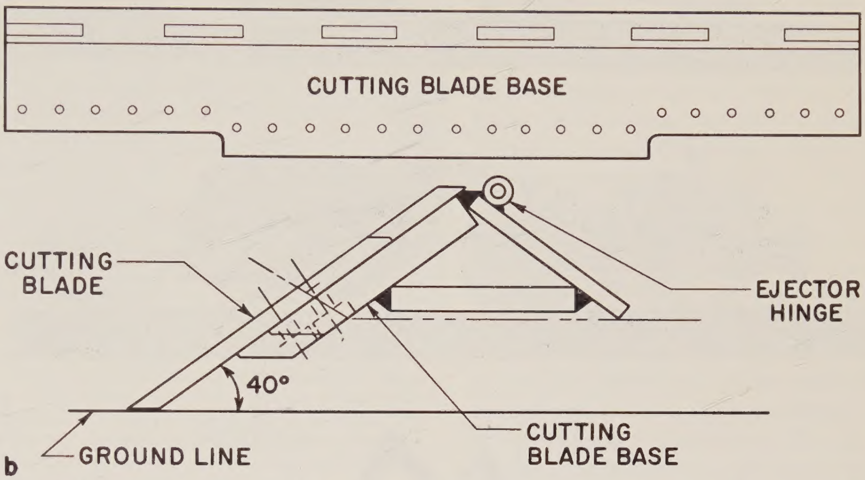
The end of World War II brought about an era of wide-scale earthmoving projects and with it the need for scrapers of increased capacity. The successful application of twin power to Euclid trucks in 1946 paved the way for the development of Euclid's first twin engine carry-scraper.

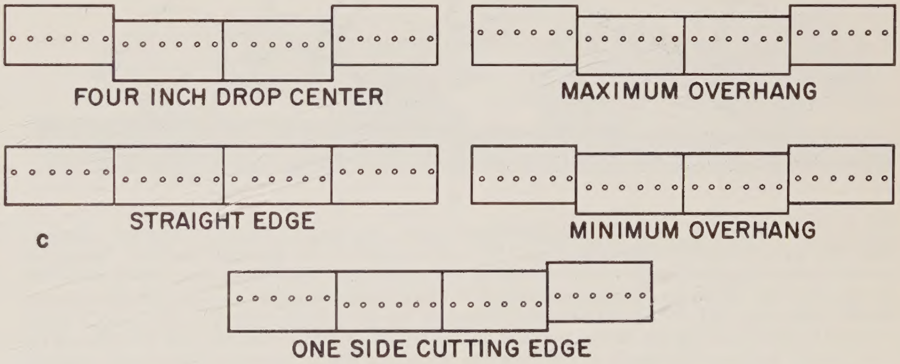
The 1949 Euclid twin engine carry-scraper (Fig. 1a) was comprised of 3 main sections: (a) the 4-wheel tractor to pull the scraper, (b) the scraper assembly, and (c) the engine at the rear of the scraper. The present Euclid TS-18 twin engine scraper (Fig. 1b) also is comprised of the same 3 sections with the exception that the 4-wheel, 2-axle, rear-wheel drive tractor is replaced by a 2-wheel, power steered, single-drive axle tractor. (At the time of the 1949 developmental program Euclid had available a field-proven 4-wheel tractor used to pull bottom dump earth hauling trailers, and it was decided to use this as the forward power train for the scraper.)

The major problems in the design of the twin engine carry-scraper involved adapting the forward and rear engines, with their separate power train components, to the scraper assembly. The overall design of the scraper assembly, consisting of the scraper bowl, apron, and ejector (Fig. 6), remained basically the same as that used on the Euclid scrapers prior to the twin engine development. The major problem here concerned designing the assembly to provide the required increase in capacity.

Fig. 7—The ejector component of the scraper assembly is hinged at the base of the cutting blades (*a*). The cutting blade base and blades, in turn, are positioned approximately 40° to the ground surface (*b*) and are so designed that one type of blade can be used for various types of blade arrangements (*c*). Each blade arrangement is used for a specific type of scraper operation. The 4-in. drop center arrangement is used for hard, rock-free soils. The straight edge arrangement is recommended for a level cut or level fill, such as is necessary for land leveling and dressing of the grade. For rapid loading in loose, rock-free soils, the maximum overhang arrangement is preferred, while minimum overhang is recommended for rocky soils. The 1-side cutting edge arrangement can be used for pioneering scraper cuts on side slopes or to crown a scraper cut.







Drawbar Pull Is Major Factor in Loading a Scraper

While the mechanics of loading a scraper, based on the scoop principle, are quite involved and are applied in the light of actual experience as to scraper loading characteristics, the primary factors to consider are the shear resistance of the earth material and the drawbar pull available. The cutting blade edge of the TS-18 scraper is mounted at an approximate 40° angle to the ground surface (Fig. 7). The cutting edge exerts upward thrust on the earth material during the loading operation of the

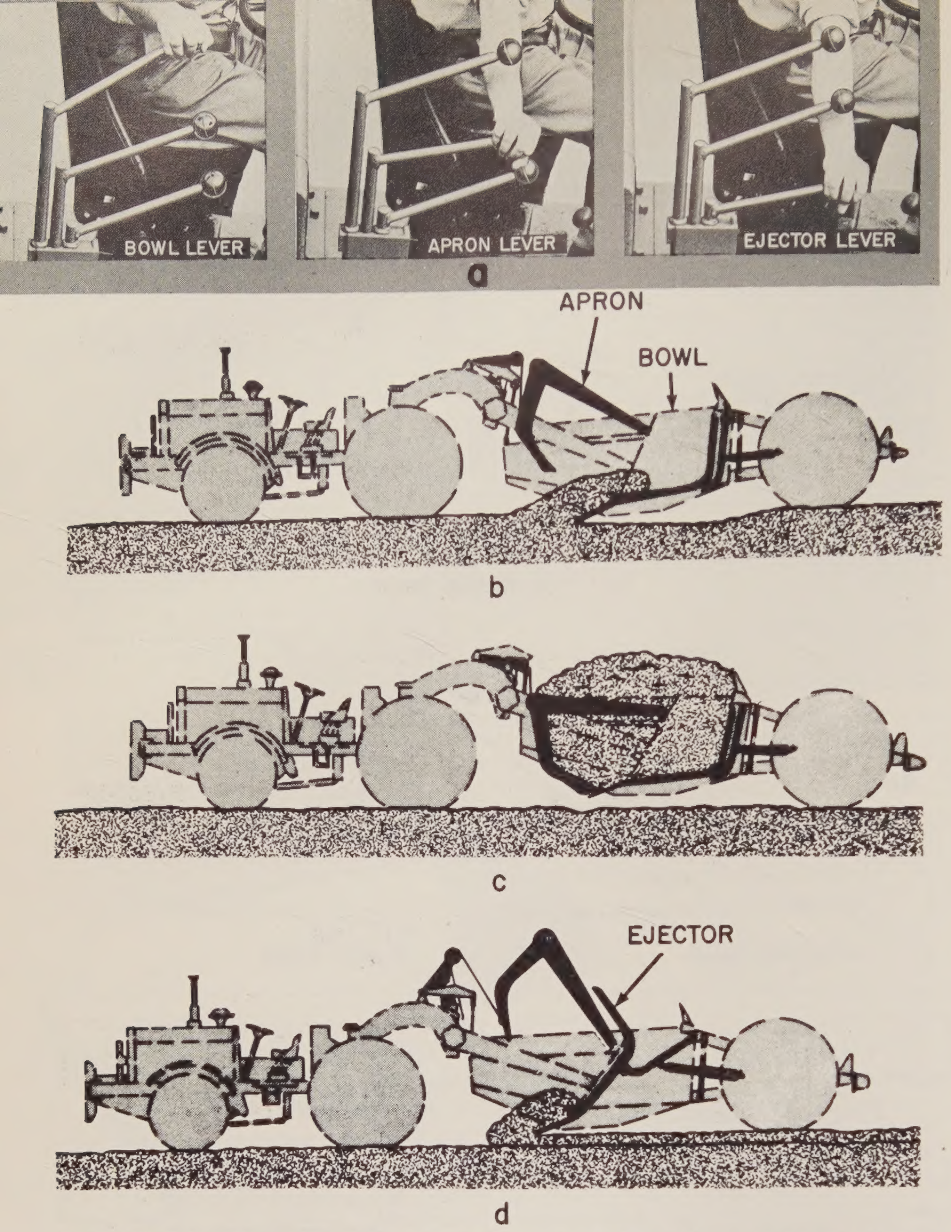


Fig. 8—The independent actions of the scraper bowl, apron, and ejector during a loading and unloading operation are controlled by individual control levers (*a*) located on the operator's platform. Before the scraper enters a cut, the ejector is fully lowered and the apron raised a sufficient amount to allow the cut to enter the bowl. When the scraper enters the cut, the bowl is lowered until the cutting blades reach the desired depth of cut (*b*). As the scraper proceeds through the cut with the cutting blades lowered, dirt is loosened by the blades and forced into the bowl by the forward motion of the unit. The dirt entering the bowl "boils" back into the ejector and forward into the apron. When the bowl is filled (*c*), the apron is lowered to act as a retainer and the bowl is raised a sufficient height to clear any obstructions in the haul road while the load is being transported to the fill. As the scraper approaches the fill, the bowl is lowered until the scraper blades are at the correct distance above the ground to give the desired depth of fill (*d*). When the load is ready for ejection, the apron is raised to a position where it is just able to clear the load being dumped. The ejector is then tipped forward about its hinge points at the base of the cutting blades to complete dumping of the load.

scraper's work cycle (Fig. 8) which is approximately equal to the forward thrust of the scraper. This thrust, in turn, is limited by the shear resistance of the earth material. As the dirt enters the bottom of the bowl, it becomes necessary for the entering dirt to shear through or raise up the dirt already in the bowl.

Although it is an over-simplification, it can be stated that, in general, the size of the load which can be loaded in a reasonable time (approximately 4 to 5 sec per cu yd when self-loading) is proportional to and limited by the available drawbar pull. The 4-wheel drive design of the TS-18 scraper makes available (depending on the tire-to-ground coefficient of friction) approximately 60 per cent of the scraper's gross weight. The capacity of the scraper bowl of the TS-18 is between 60,000 lb and 75,000 lb. The gross vehicle weight of the overall unit is 138,000 lb. The tractive ability of the TS-18, therefore, is equal to 138,000 lb x 0.6 (coefficient of traction), or 88,800 lb. In contrast, a single engine scraper of the same bowl capacity has a drawbar force of 70,000 lb (weight on 1 drive axle) x 0.6 or 42,000 lb available.

Scraper Assembly Components Hydraulically Operated

The individual operations of the scraper bowl, apron, and ejector components during each phase of the work cycle are independently controlled and operated by single-acting, single-stage hydraulic jacks activated by individual control levers mounted on the operator's platform.

Two methods for the control and operation of these 3 components were considered at the time of the development of the twin engine scraper: (a) cable control and (b) hydraulic control. The established method at the time of the development used a 2-drum cable power control unit. This method had a disadvantage, however, in that a single cable was used to control the operation of both the apron and ejector. This did not allow for independent action of these 2 components. Euclid decided to use a hydraulic system to achieve the independent action desired.

The TS-18 scraper hydraulic system is composed of a hydraulic oil supply tank; a pump; control valve; control levers for each scraper assembly component; oil pump; and the hydraulic jacks which activate the scraper bowl, apron, and ejector (Fig. 9). The system is designed so that the hydraulic steering system of the scraper also receives its oil supply from the same tank. The hydraulic pump is directly driven by the engine and runs at engine speed at all times.

The 4 jacks used to actuate the scraper bowl, apron, and ejector are identical in design. The scraper bowl is operated by 2 jacks, and the apron and ejector are each controlled by a single jack (Fig. 10). The jacks for the scraper bowl and apron are mounted vertically on the pull yoke of the scraper, while the hydraulic jack for the ejector is mounted in the scraper's tail assembly.

3 Major Problems Involved in Twin Engine Scraper Development

The adaptation of the twin power principle to a carry-scraper presented

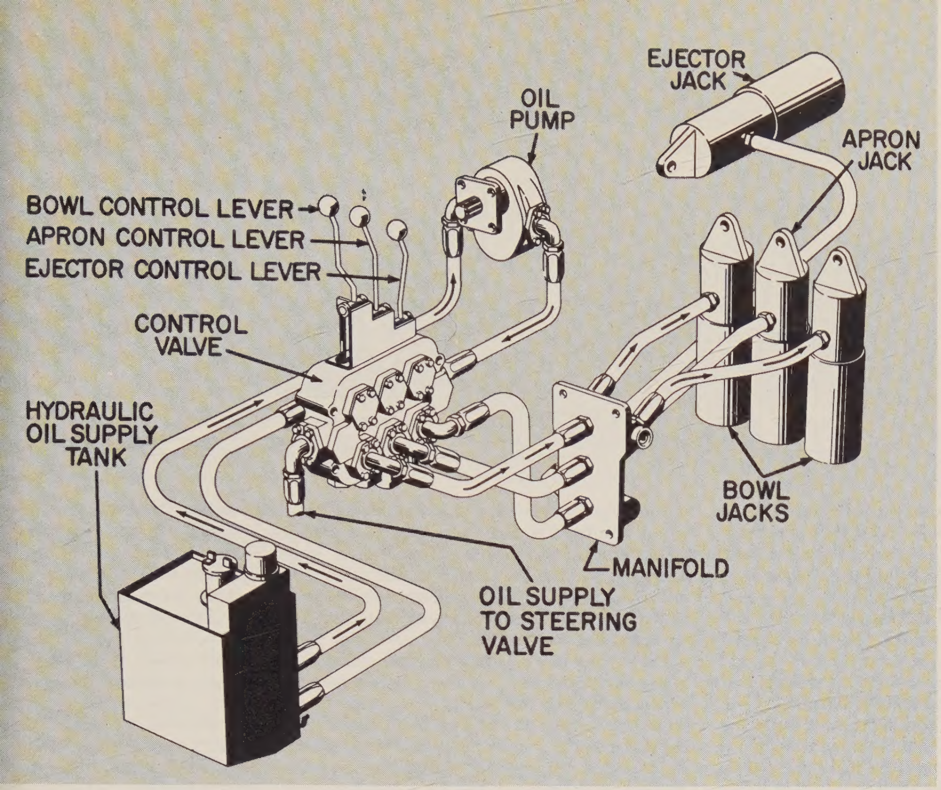


Fig. 9—This schematic drawing of the scraper hydraulic system illustrates the manner in which oil is supplied to the 4 hydraulic jacks used to activate scraper bowl, apron, and ejector movement. When one of the control levers is pulled by the operator, a valve plunger, connecting the lever to the control valve, is pulled out of the control valve and opens a passage which allows oil to flow from the pump to the manifold, where it is then distributed to the hydraulic jack corresponding to the control lever pulled. The hydraulic steering system also receives its supply of oil from the same tank used for the scraper system. Whenever one of the control valve plungers is activated, however, oil flow to the steering system is shut off. During this condition, oil is supplied to the steering system by an oil booster-pump.

problems which were more complex than when the principle was first applied to the truck development. Separation of the forward and rear engines by the scraper assembly presented problems dealing with synchronization of the front and rear power trains and their adjoining components, remote control of the rear engine, and rear engine intake-air supply and filtration.

Power Train Synchronization

The main components of the power train for both the 1949 and present TS-18 carry-scraper remain basically the same with the main difference being in their installation location due to the overhung engine design change (Fig. 11). The main components of the power train consist of the 2, 6-cylinder front and rear Diesel engines; the Allison torque converter and Torqmatic transmission used in conjunction with each engine; the front and rear driveline units each comprised of a universal joint, a propeller tube, and a slip joint; and the front and rear drive axles.

The solution to the problem of the best method to use for synchronizing the front and rear power trains was found in the use of torque converters on each fore and aft power train. The Allison torque converter represents an ideal power transmitter for each of the 2 engines to be synchronized to propel the vehicle because, while always attempting to accelerate itself into a coupling state, it constantly multiplies torque while running under conditions which tend to prevent it from reaching the coupling state, thereby compensating for such variables as engine rpm and tire rolling radii. The Allison converter allows each power train to shoulder its share of the load.

Allison Torqmatic Transmission

The Allison Torqmatic transmission used in conjunction with the fore and aft torque converters operates on the principle of engaging and disengaging multiple-disc clutch plates, by the application of hydraulic pressure, which lock or release components of a compound planetary gear-train system to give the necessary gear reduction ratios required to obtain optimum performance under various operating conditions. With the torque converter to cushion the shock, quick-shifting under load through the 3 forward and 1 reverse speed ranges is easily accomplished—a feature which is extremely valuable when accelerating and up-shifting under scraping conditions of high-rolling resistance.

The desirability of having the operator use the same transmission shift lever to shift simultaneously both the forward (tractor) engine transmission and the rear (scraper) engine transmission into the desired gear ratio presented a problem as to the method for controlling the flow of oil into each transmission. Mechanical linkage was designed to operate the spool-type transmission control valve on the tractor transmission. The use of a similar linkage to operate the oil-flow control for the rear transmission, however, was not practical. The problem was overcome by redesigning the oil flow control valve for the rear transmission so that the gear shifts are controlled by the action of electric solenoids. Four solenoids are used—1 for each forward gear and 1 for the reverse gear. When any 1 of the solenoids is energized, it opens the valve which, in turn, allows oil at a pressure of 120 psi to engage the clutch plates and put the unit into gear. The electric circuit used to energize each solenoid is controlled by a micro-switch mounted on the transmission shift lever. This lever has a mechanical linkage to the forward transmission which simultaneously energizes the micro-switch controlling the rear transmission. A switch also is mounted on the tractor dash panel which allows the solenoid operated valves of the scraper transmission to be disconnected whenever service conditions require that the rear engine not be used.

Differential

The differential used with each drive axle of the twin engine carry-scraper is designed to perform 3 functions: (a) change the direction of power by 90° from the transmission to the drive-axle shafts, (b) increase torque at the wheels, and (c) permit a difference in rotational speed between the 2 wheels on each drive axle when the vehicle makes a turn. Located in the hub of each wheel is a planetary gear system which first multiplies the torque delivered by the differential and then applies this torque to the wheels.

When the first twin engine carry-scraper was tested in the field under severe operating conditions, results indi-

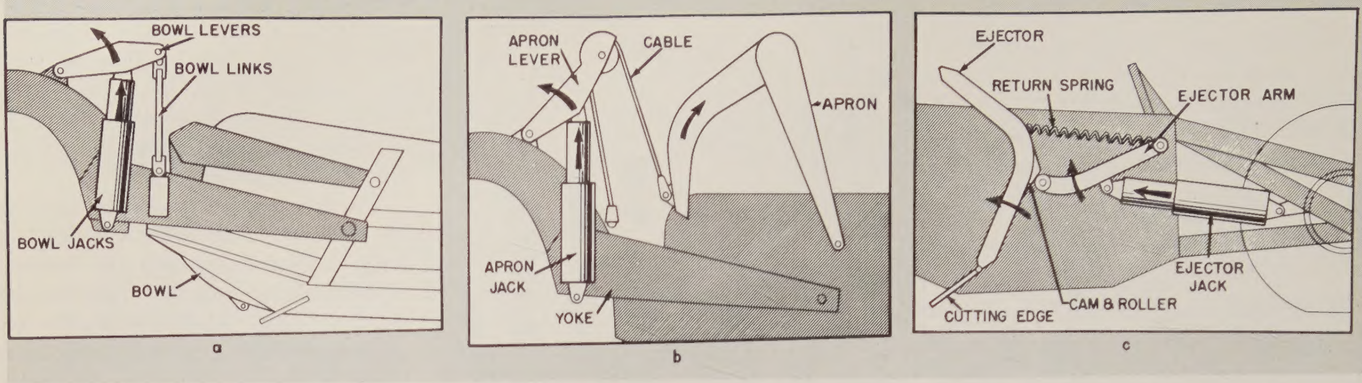


Fig. 10—The scraper bowl, apron, and ejector components are activated by hydraulic jacks. The jacks used to raise the scraper bowl and apron are mounted on the pull yoke of the scraper. The bowl is raised by the 2 outside jacks mounted on the yoke. These jacks are connected to the bowl by a lever and link arrangement (*a*). When the bowl control lever is pulled by the operator, oil pressure is applied to the jacks and forces their pistons to extend and push the levers upward, thereby creating a pulling action on the links to raise the bowl. The apron is raised by means of the center jack mounted on the pull yoke. This jack is connected to the apron by means of a lever, sheave, and cable arrangement (*b*). When the operator pulls the apron control lever, oil pressure is applied to the jack. As the piston of the jack extends, it raises the lever which is pivoted at one end to the scraper's pull yoke and mounts a sheave on the other end. A cable is anchored to the pull yoke and runs up over the sheave and down to the "lip" of the apron where it is attached. The ejector is controlled by means of a hydraulic jack mounted between it and the rear wheel axle-bracket strut (*c*). When oil pressure is applied to the jack, its piston extends and pushes against a lever which is pinned at one end to the scraper bowl and has a roller on the other end which rolls on a cam surface on the back surface of the ejector. As the jack forces the lever forward, the ejector, in turn, is tipped forward about its base. This forward movement of the ejector serves to "roll out" instead of push the load through the bottom of the scraper bowl. The cam surface increases the dumping force at the start, and, as the lever reaches the end of its stroke, it rolls over a section of the cam which accelerates the ejector just prior to hitting the ejector stops which imparts a "snap" to the ejector to shake loose any remaining material. To assist the ejector to return to its lowered position, a return spring is used and is connected between the scraper bowl and ejector. The 4 jacks used are identical in design and their component parts are interchangeable.

cated that the differential performed in a highly satisfactory manner except when one wheel encountered less resistance to rotation than the wheel on the opposite end of the drive axle. When this condition occurred, the differential planet gears rotated about the gear which was reluctant to revolve. The rotating planet gears, in turn, drove the wheel encountering less resistance at a greater rotational speed, resulting in a condition of "wheel spin" or "spin out" which served to rob the axle of its drawbar pull. This condition of decreased drawbar power restricted the operation of the scraper, particularly when self-loading.

To remedy this situation, Euclid engineers employed the use of a No Spin differential which is basically a planetary gear arrangement in which the planet gears are replaced by a pair of over-running clutches. These clutches allow the outside wheel, when making a turn, to be driven by the ground and over-run the inside wheel which is driving the vehicle. When the conditions conducive to wheel spin occur, the No Spin differential automatically directs full torque to the wheel having the best tractive ability.

Remote Control of Rear Engine

The prime objective in developing a system for the remote control of the rear engine speed was simple and dependable operation. Since the Allison torque converters allow the 2 engines to run at different speeds and because most scraper operations are performed under full throttle operation, extreme sensitivity of the remote control system was not required.

The first remote control system designed used a hydraulic master cylinder and slave cylinder arrangement. Because of difficulty encountered with bleeding the air out of the system and the expansion characteristics of the long sections of hose required, considerable "sponginess" in the control occurred.

To correct this situation, a pneumatic system was designed which proved to be successful and has been used on all twin power scrapers built to date. In the pneumatic system, the master cylinder is a spring-regulated, master treadle-valve connected to a 100 psi air system. For a given treadle-valve position, a specified air pressure is metered through connecting hoses to a slave cylinder which, in turn, assumes a specific setting to suit the air pressure to which it is subjected. The motion of the slave cylinder is transmitted to the accelerator control on the rear engine by means of a mechanical linkage arrangement. This linkage also serves both as a manual control and manual rear engine shut-off.

To control the speed of both the front and rear engines, the rear engine accelerator pedal is mounted adjacent to the front engine accelerator pedal which is connected to the front engine by mechanical linkage. The operator straddles both pedals with his foot and rolls his ankle to one side or the other to run one engine at a different speed than the other.

Rear Engine Uses Special Air-Intake and Air Cleaner Arrangement

Providing clean air to the rear engine for efficient combustion presented a problem on the twin engine carry-scraper because of the dust primarily from the tractor wheels which enveloped the engine when the scraper traveled over dry, dusty ground. The problem here consisted of: (a) providing a sufficient amount of clean air to the rear engine and (b) developing high-efficiency air cleaners to remove dust and dirt particles.

The initial method for providing a sufficient amount of clean air to the rear engine was to pipe it back to the rear engine from a point near the front of the scraper. Because of the lengthy duct work required it was decided that this was not a very practical solution, although this method has been used in a few cases where operation under extreme dust conditions or where specialized job conditions have limited the maximum overall height of a scraper.

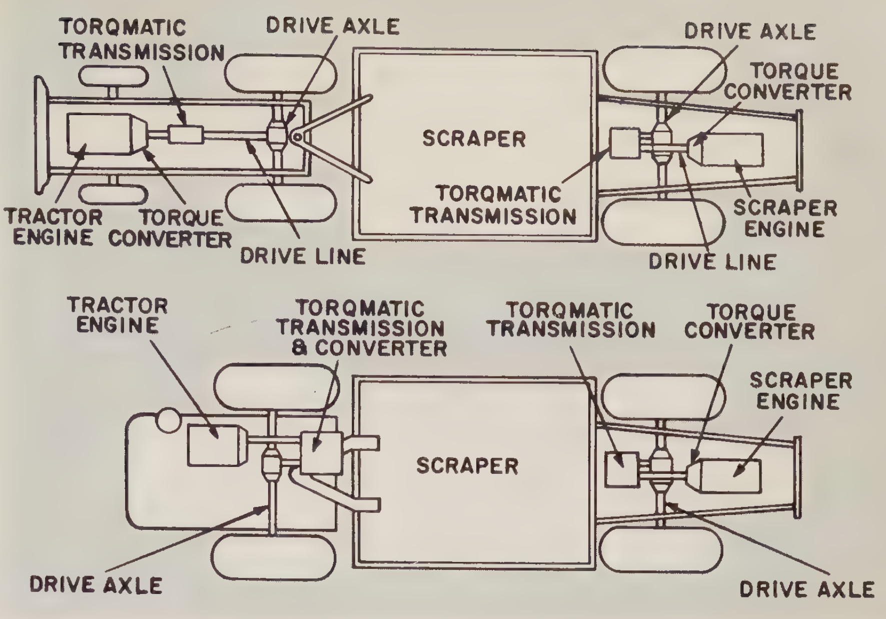


Fig. 11—These 2 sketches illustrate the installation layout of the power train units on the 1949 twin engine scraper (top) and the present day TS-18 overhung engine scraper.

The use of flexible or "knockdown" air-intake pipes was then attempted. This solution, however, was not too satisfactory. A design finally was developed based on the use of a telescopic stack which can be adjusted to several height ranges.

The attempt to obtain acceptable filtration of intake air for the rear engine, and also the front engine, has been a more difficult and continuous problem. This is because of the increased capacity of air required for the TS-18's higher horsepower Diesel engines and the limited space available for installing the air cleaners.

The pilot model of the first twin engine scraper had a single oil-bath type air cleaner used in conjunction with a centrifugal type of pre-cleaner. Field tests indicated that this system did not provide sufficient filtration for the rear engine, and a secondary oil-bath cleaner was added in series with the primary cleaner. Further tests in the field disclosed that the pre-cleaner, although removing a substantial amount of dirt from the air passing through, also broke some of the dust and dirt down into finer particles which passed on through the pre-cleaner and which the oil-bath primary and secondary cleaners were unable to trap. This situation resulted in a lower overall cleaning efficiency, and it was decided to eliminate the pre-cleaner from the air filtration system.

The next attempt at solving the problem used a design which incorporated removable screens in the air cleaner to facilitate easier cleaning. A further refinement used a venturi-tray in the air cleaner which improved air flow characteristics through the oil bath. Dry-type air cleaners also have been tried without too much success to date.

After reviewing the advantages and disadvantages of the various filtration-system designs used, Euclid engineers formulated a final design based on the use of 2 combination wet- and dry-type air cleaners piped in series to the engine. In this design, the wet section of the cleaner removes the heavy mass of dirt particles, and the dry section of the cleaner, mounted in the same housing and acting as a secondary cleaner, filters the finer particles.

Air Alarm System Warns Operator of Malfunction in Power Train Components

Because of the importance of maintaining safe engine, converter, and transmission operating conditions, it was deemed desirable to have a warning system to inform the operator when an unsafe condition was present in either the fore or aft power train units. Gauges on an instrument panel could be connected to the front engine and transmission and could be seen easily by the operator. However, the remote location of the rear engine and transmission prohibited this system for the rear components.

The original warning system design for the rear power train used tell-tale lights as a danger signal to the operator whenever the engine or transmission was being operated exceeding safe limits. This system lacked dependability, however, due to the possibility of the light bulbs burning out.

To provide a more dependable warning system, an air-alarm system was designed and is now in use. This system uses pressure-sensitive and temperature-sensitive valves installed in the engine coolant manifold, the torque converter manifold, and the engine lubricating system. These valves, in turn, are connected by air lines to an air horn mounted on the rear of the scraper. If the temperature of the engine coolant system or the converter oil rises above a safe limit or the engine lubricating oil pressure falls below a safe limit, the air horn blows, warning the operator. Pressure and temperature gauges mounted on an instrument panel located adjacent to the engine on the rear of the scraper aid the operator in locating the source of trouble.

Summary

The problems involved in the development of the Euclid TS-18 scraper centered about adapting the twin engine, 4-wheel drive principle, as used on Euclid trucks, plus the established basic design of the scraper assembly to meet the specific requirements of an earthmoving carry-scraper. Once the basic overall design had been established, it then became necessary to solve individual problems connected with synchronizing the front and rear power trains, remote control of the rear engine, and hydraulic control of the scraper assembly components to allow independent action.

The evolution of the present-day earthmoving carry-scraper spans a period of approximately 110 years. The first 100 years saw an increase in capacity from ⅛ cu yd to 12 cu yd and an increase in hauling speed from 2 mph to 15 mph. In the last 10 years, however, the capacity of the scraper has doubled from 12 cu yd to 24 cu yd and the hauling speed has increased from 15 mph to 30 mph. What the future holds will depend on the development of new ways for providing and utilizing the necessary power to move greater loads. The capacity of today's scraper units can be increased, but exactly what the increase will be depends to a great extent on the drawbar power available for turning the wheels.

How Standards Are Prepared for Stream Pollutant Spectrodetermination

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Spectroanalysis is a subtle and versatile tool, but its application to quantitative analysis of polluted waters demands the preparation of standard materials which are equivalent to residues from polluted waters of known composition. This paper discusses the principles underlying the preparation of such "standards" particularly as they apply to a stream pollution survey in the Miami River Valley area of southwestern Ohio. The procedure for making these standards was developed at Delco Products Division for the analysis of its own storm and sanitary sewer effluents. The method was later adapted for the particular needs of an area-wide stream pollution survey in which the Division cooperated.

Laboratory procedure saves time in stream pollutant analysis

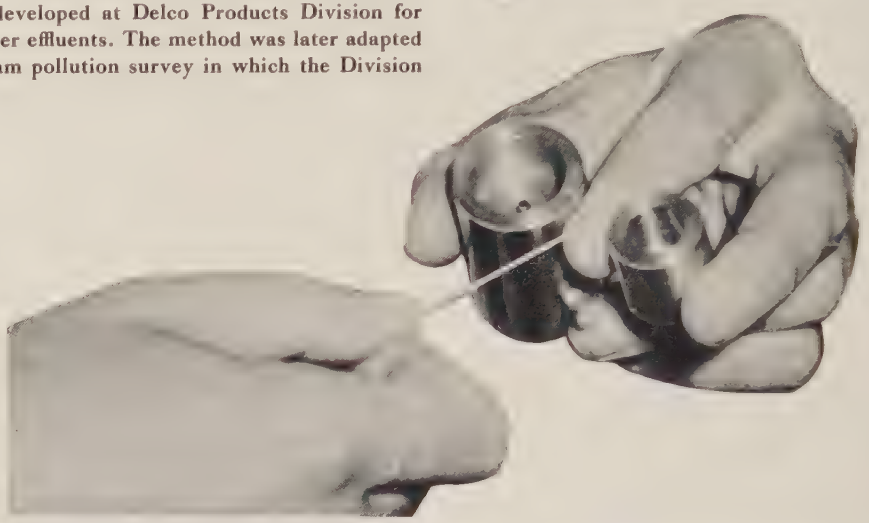


Fig. 1—In preparing a sample for arcing, powdered residue is first mixed with an equal weight of pure graphite and then tamped into the cavity of the electrode by the electrode loader shown. Also shown are the electrode holders.

IN QUANTITATIVE spectroanalytical work it is necessary to have or to prepare a mixture of known composition in a form which will be chemically and physically equivalent to some derivative from a sample of unknown composition. This general principle is well known and has been applied to many specific problems in spectroanalysis. At Delco Products Division a specific procedure has been developed for application to the general problem of stream pollutant analysis.

In most stream waters the total positive ions in a sample will not exceed 0.1 per cent. At such a concentration it is seldom possible to achieve reasonable sensitivity by solution excitation, especially when some micropollutants in the range of 1 part in 20 million are to be determined. The sample, therefore, must be concentrated, since by the simple expedient of evaporation an enrichment of at least 1,000 to 1 is assured. Probably no absolutely general procedure for such analyses can exist. Individual analysts will argue the merits of solution excitation with porous electrodes, the use of absorbent electrodes, and other methods, any of which may be used with satisfactory results for specific problems. The choice may be no more than personal preference, unless the concentration sought is below the limit of sensitivity for a specific element.

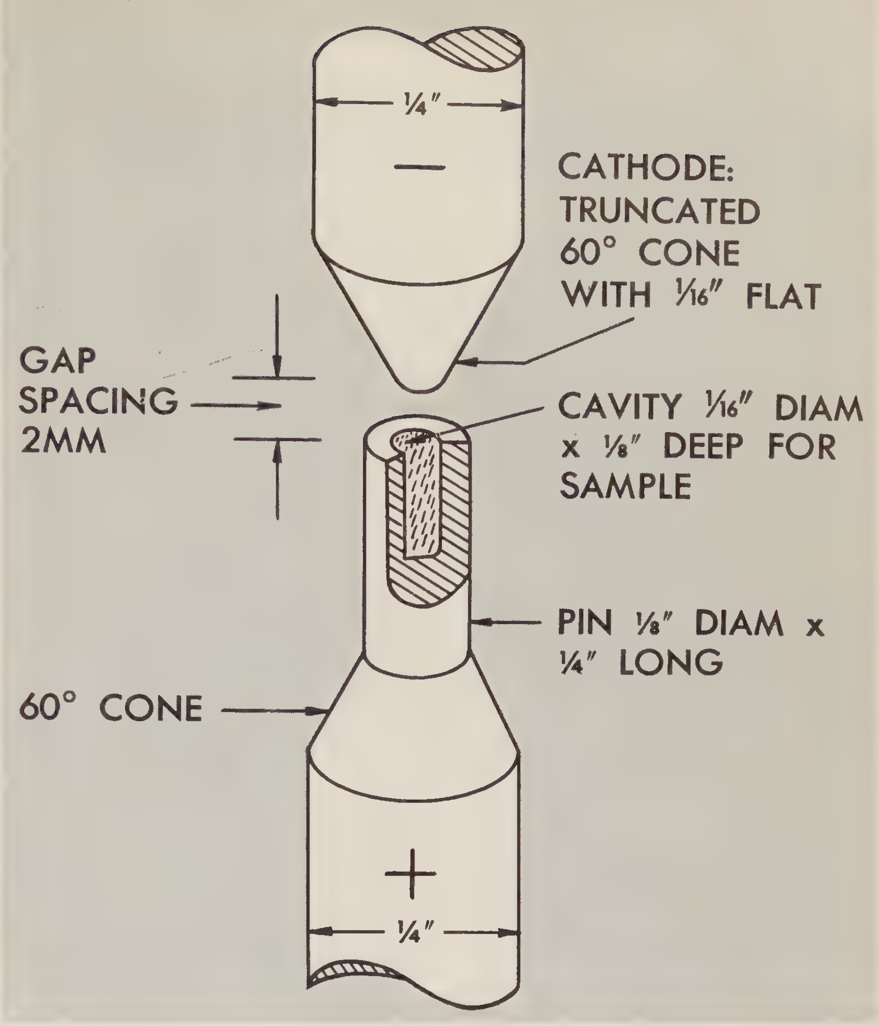
Preparation of the Sample for Arcing

An analytical scheme for determining variable trace components in a matrix of approximately constant composition by d-c arc spectroanalysis requires a 4-step procedure. It is necessary first to establish a base composition whose excitation characteristics are substantially unaltered by minor variations in macro- and microconstituents, including interfering ions not sought in the analysis. To such a base, known amounts of the various microconstituents are then added, with the concentrations making up a geometric series covering the expected range of variation. Next, an internal standard element is selected and added. Finally, the mixture is processed in a manner to produce an end product chemically and physically similar to some easily prepared derivative of the sample. The number of standards necessary in a set is dependent upon the concentration ranges to be covered and upon the number of elements to be determined.

Spectroanalytical methods utilizing concentrated solutions of an unknown are always subject to solubility problems. There are, therefore, obvious advantages to the use of solid derivatives from the unknown. This procedure is built around the following preparation of a sample for arcing:

(a) A sample of 200 ml is acidified with a few drops of hydrochloric acid and evaporated nearly to dryness
(b) The internal standard is added, and the sample is transferred to a platinum crucible
(c) Sulphuric acid is added, and evaporation is continued to dryness
(d) The sample is ignited at 1,500° F
(e) The residue is ground in a mortar to a fine powder
(f) The powdered residue is mixed with an equal weight of pure graphite and tamped solidly into the cavity of an electrode (Fig. 1)
(g) The sample is excited in the d-c arc at 7 amp to 10 amp without pre-arcing (Fig. 2).

At the same time that the sample is arced, a group of similarly prepared



¼″
—
CATHODE: TRUNCATED 60° CONE WITH 1/16″ FLAT
GAP SPACING 2MM
CAVITY 1/16″ DIAM x 1/8″ DEEP FOR SAMPLE
PIN 1/8″ DIAM x ¼″ LONG
60° CONE
+
¼″

Fig. 2—This schematic drawing illustrates the arrangement of graphite electrodes for d-c arc excitation of samples and standards.

standards is excited in the same manner. Before considering the mechanics of preparation, it is necessary to make a thorough study of the "normal" composition of the stream water and the reactions it may be expected to undergo during the process of sample reduction. A stream of water almost inevitably will contain perceptible quantities of sodium and calcium, along with potassium and magnesium in smaller amounts and probably aluminum and iron. Before the analyst can prepare a valid set of standards, he must know the approximate concentration of these elements, especially those which tend to dominate the arc discharge. He also must know what negative ions are present. Volatile ions, such as chloride and bicarbonate, will be removed during the concentration process, but ions, such as phosphate and silicate, and some borate will remain.

It is not necessary to reproduce all the ions present in a sample to prepare a valid standard series. Only those ions whose presence affects the character of the arc need be included. Sodium and calcium are dominant as respects arc temperature and, when they are preponderant, act as stabilizers. If considerations of sensitivity permit, it often may be desirable to use salts of these elements as diluents to such an extent that they will comprise more than ¾ of the metallic components in a mixture.

Phosphates create a problem. The arc conditions used in this procedure are strongly reducing. Some of the impurity elements may be quite stable as pyrophosphates and, therefore, less reducible than when present as oxides or sulphates. Thus, it is highly important to know the phosphate content in a stream water. If the amount is variable, it is necessary to add phosphate to the samples and an approximately equivalent amount to the standards. It may make a great difference to some element line intensities if phosphate varies from 5 parts per million (ppm) to 30 ppm, but the effect is negligible if the range is from 205 ppm to 230 ppm.

The principle of adding an excess of an interfering ion is often useful, but it is not universally applicable. When very low concentrations must be determined, such dilution may be intolerable, and separation techniques must be used. It must be remembered, however, that the determination of pollutants at micro concentrations is not necessarily a microanalysis problem as such. Even at 0.05 ppm a pollutant will represent 0.01 per cent of the total weight of residue concentrated from a water with 500 ppm total solids.

A Case Study of Spectrodetermination of Stream Pollution

An extended study of stream pollution in the Miami Valley Water Shed Area was undertaken in the fall of 1954. As part of that program it was necessary to run analyses on several hundred water samples for zinc, lead, nickel, copper, chromium, and cadmium in the range from 0.05 ppm to 6.0 ppm and for iron from 0.05 ppm to 14.0 ppm. Investigation showed that the water contained perceptible amounts of sodium, potassium, calcium, aluminum, and magnesium principally as chloride, sulphate, and bicarbonate and that phosphate was present in negligible concentration.

The concentration of these ions varied, but a reasonable average was attained in the following mixture: sodium 16 ppm, potassium 4 ppm, calcium 120 ppm, aluminum 5 ppm, and magnesium 30 ppm.

The next problem was the selection of a suitable internal standard for the determination of the 7 pollutant elements in such a matrix. (These elements vary widely in their boiling points, ranging from 778° C for cadmium up to 3,000° C for iron.) It was apparent that no single element would serve as an optional standard for all of them. For the greatest possible accuracy it would have been best to use 3 standards, such as barium for the volatiles, gallium for the intermediates, and cobalt for the more refractory elements. In some cases such multiple standards may be practical, but in this one a single standard, gallium, was chosen. The use of barium was considered but rejected because of the manipulation problems arising from the insolubility of barium sulphate. Gallium had several advantages. It was not present in any of the samples; it did not create any special problems due to its chemical properties; and its ionization potential was reasonably close to those of the other elements concerned.

Setting Up the Ratio of Pollution Elements

After the determination of a "normal" matrix composition and a suitable internal standard, the apportionment of the pollutant elements in the various individual standards was considered. Since 6 of the 7 elements were expected to fall in the 120-fold range of 0.05 ppm to 6.0 ppm, the optimum values for the individual standards were derived by setting up a geometric progression in which the extremes were the first and last members and in which the number of terms equalled or surpassed the number of elements to be determined. Further necessary restrictions were imposed by the following considerations:

(a) The total of all pollutant elements should be approximately constant in all the standards

(b) The standards should have such a composition that their arc behavior will be dominated at all times by the matrix elements. For this reason an arbitrary maximum of 15 per cent for total pollutants seemed reasonable

(c) The ratios of pollutant elements in the various standards should vary with respect to each other

(d) The step ratio between various concentrations of any given element should not exceed $\sqrt{10}$.

In the particular problem under study, these conditions were met without difficulty by using a set of 7 standards, each containing all of the pollutant elements. In such a case the geometric ratio for iron was $\sqrt[6]{14/0.05}$, or approximately 2.56, while for the other elements the ratio was $\sqrt[6]{6/0.05}$, or about 2.22. The addition of an eighth standard in the set, containing iron as its only additive, was made. This additional standard was attractive because it preserved a common ratio for all the elements and a nearly constant sum of impurities, but it was not entirely necessary.

Assigning Values for Individual Standards

After selecting the ratio to be used, values for the specific standards were assigned (Table I). Values were assorted in a random manner, but the ratios of the pollutants had to vary with respect to each other.

In addition, each standard contained a nonvariant matrix of 16 parts sodium, 4 parts potassium, 120 parts calcium, 5 parts aluminum, and 30 parts magnesium, plus a quantity of the internal standard element sufficient to bring up several of its lines at intensities suitable for analytical use. One ppm gallium met this requirement. A ninth standard was added containing none of the pollutant elements but having the internal standard. As a check on reagent purity a smaller amount of a tenth standard containing matrix elements only was included in the scheme.

It is seldom necessary to use reagents of unusual purity for the preparation of standards. Compounds of sodium, potassium, calcium, magnesium, and aluminum are available, which can be used without further purification. For sodium and potassium, the chlorides can be weighed directly. For aluminum it is possible to get high purity metal of 99.99 per cent, but it is more practical to use a solution of the nitrate which has been assayed to determine the percentage of metal. In this specific case, any preparation of aluminum nitrate was satisfactory in which the impurity elements were present in concentration equivalent to 1/10 of the lowest concentration of each impurity element. Thus, the presence of 0.01 per cent iron in the crystalline aluminum nitrate was not troublesome.

Magnesium was conveniently weighed out as the oxide and calcium as the carbonate. Both were dissolved in hydrochloric acid. The 5 matrix elements in their proper proportions were made up in a master batch in sufficient quantity for all the standards. The mixture was checked spectrographically to insure adequate purity. At this point only nitrates and chlorides were supposed to be present in the solution.

Preparing Standard Solutions of the Pollutants

The next step was the preparation of standard solutions of the pollutant elements. Zinc, lead, nickel, copper, cadmium, and iron were weighed directly as analytical reagent purity metals and dissolved in nitric acid or aqua regia. Chromium was best weighed approximately as the trioxide, but the solution had to be assayed. This can be done either volumetrically with ferrous ammonium sulphate or colorimetrically by comparison with a weighed amount of dried potassium dichromate in tetranormal nitric acid having a composition of 25 ml HNO_3, sp gr 1.42, and 75 ml H_2O. Element concentrations of approximately 2 per cent were most convenient for this phase of the preparation. Gallium for this purpose was made up from the pure oxide, weighed as Ga_2O_3, which was easily dissolved in 50 per cent sulphuric acid. It was advisable to make up an additional quantity of the internal standard element solution which could then be further diluted for use in analyses.

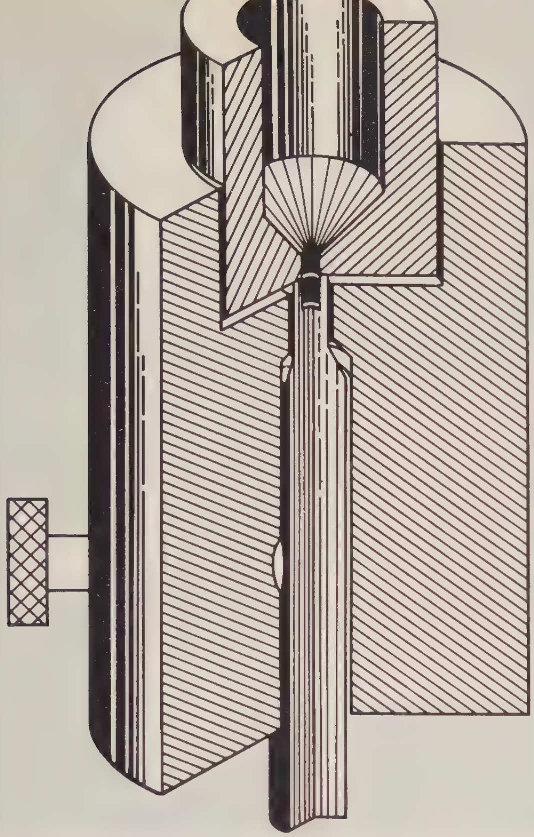
After all solutions were prepared and checked for purity, they were combined to obtain mixtures having the required compositions. To each mixed solution was added a quantity of sulphuric acid, about double that needed to form sulphates with the mixtures. A precipitate of calcium sulphate formed immediately but did not interfere with the preliminary evaporation of the solution. The beaker was covered with a watch glass and heated on a hotplate at a moderate temperature, with the heat increasing gradually until fumes of sulphuric acid appeared. At this point the beakers were transferred to a convection oven at 175° C for at least 15 hr to remove the excess sulphuric acid. Since rapid drying causes the salt cake to form in a shape which will adhere to the walls of the beaker and is difficult to remove, the slow drying process was used. This produced a cake which shrunk away from the beaker as it dried and was easily removed.

The entire cake was transferred to a large platinum dish. The beaker was thoroughly scrubbed out with distilled water, and the scrubbings were added to the cake in the dish. The cake was dried further at 250° C for about 1 hr and then placed in a muffle furnace at 915° C for about 45 min. During the ignition, large volumes of sulphur trioxide were evolved. When ignition was complete, the cake had become a hard, almost glassy mass which had a decided tendency to adhere to the platinum dish. The dish was cooled and inverted on a clean glass plate, and the bottom of the dish struck with a rounded glass rod to break up the sintered mass so it could be removed. (Complete removal of the sinter is essential, and scrubbing of the partially cleaned dish followed by several repeated ignitions may be necessary to accomplish this.)

ASSIGNED VALUES FOR SPECIFIC STANDARDS

Element	Standard							
	1	2	3	4	5	6	7	8
Zinc	0.05	0.11	0.24	0.55	1.20	2.65	6.00	0
Lead	0.11	0.24	1.20	2.65	6.00	0.55	0.05	0
Nickel	0.24	2.65	0.55	0.11	0.05	6.00	1.20	0
Copper	0.55	0.05	6.00	1.20	2.65	0.24	0.11	0
Chromium	1.20	6.00	2.65	0.05	0.24	0.11	0.55	0
Cadmium	2.65	0.55	0.05	6.00	0.11	1.20	0.24	0
Iron	6.00	1.20	0.11	0.24	0.55	0.05	2.65	14.00

Table I—These concentrations are rounded off for convenience to the values of 0.05, 0.11, 0.24, 0.55, 1.20, 2.65, and 6.00. The ratio of the pollutants must be allowed to vary with respect to each other, and they should be assorted at random. Each standard also will contain a nonvariant matrix of 16 parts sodium, 4 parts potassium, 120 parts calcium, 5 parts aluminum, and 30 parts magnesium, in addition to a quantity of the internal standard element, such as gallium, to bring up several of its lines at intensities suitable for analytical use.



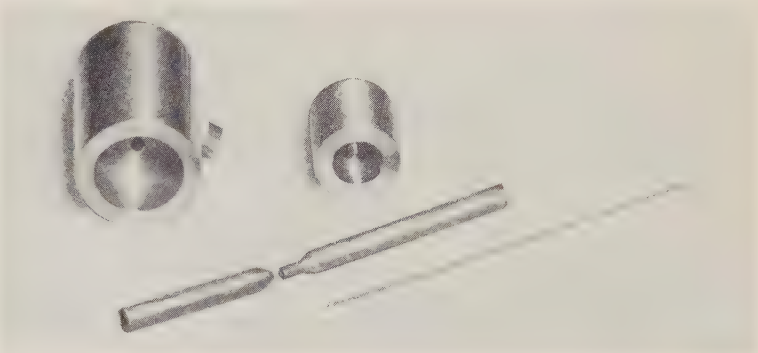


Fig. 3—The combination funnel and electrode holder (above) gives excellent results with the cavity electrode used for spectroanalysis of pollutants in stream water. The electrode is filled using a nichrome wire as a tamper (right).

Grinding of the sintered mass completed the preparation. Before starting each new run, it was necessary to clean the grinding surfaces of mortar and pestle with aqua regia, wash with distilled water, and dry. It was also necessary to guard against contamination during grinding, as many ceramics contain perceptible amounts of iron which may contaminate the standards. The grinding process was slow and had to be thorough, as the powder must be mixed completely to insure its uniformity. The standards finally were transferred to clean, stoppered containers and labelled as to composition.

Precautions Necessary to Insure Purity of Sample

During the entire preparation it was necessary to maintain the greatest caution to prevent contamination. Beakers were kept covered. Convection ovens were used in preference to forced-draft types. Glassware was cleaned and rinsed immediately before use. These necessary precautions will vary from one laboratory to another and with the identity of the matrix and pollutant elements; it is impossible, therefore, to do more than call attention to the variability of the problem.

The manipulation of moderately small amounts of samples is not a particularly difficult problem. There is more than one satisfactory solution, but the following minor points of technique may be helpful in some laboratories:

- The ground samples are scraped from the mortar with a spatula and transferred to a small watch glass for mixing with graphite
- Ignited samples are hygroscopic and should be kept in a desiccator; when samples are to be stored, gelatin capsules may be found useful
- Reproducibility is greatly improved by a standard method of loading electrodes; a combination funnel and electrode holder has given excellent results with the cavity electrode used (Fig. 3)
- Pointed counter-electrodes are not desirable for use in exposures having short or no pre-arc time because of the rapid dimensional change immediately after the arc is struck; satisfactory results have been obtained using a 60° included angle cone with its tip truncated to a 1/16-in. diameter flat.

Summary

When a large number of analyses is required, it is often worthwhile to prepare standards which will permit adaptation of spectroanalysis to the particular problem. In this particular case, 50 man hours of labor on standards preparation saved more than 1,000 hours of analytical time. The advantage of spectroanalysis for such analyses as stream pollution stems from the fact that, although the concentrations are in the micro or even ultramicro range for wet chemical procedure, they are in a very convenient working range for routine spectrographic methods. In most cases it is possible to avoid any complicated manipulation of the sample, provided only that the elements to be determined are present in detectable quantities.

Bibliography

Other related literature in this field includes the following:

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Mobile Laboratory Facilitates Tuning of Automotive Air Intake Silencers

By ROBERT H. SPAHR
AC Spark Plug
Division

Compact engineering and fabrication facilities provide for rapid field developmental tests

The quietness of the modern automobile is the end result of noise reduction at many points on the vehicle. To minimize or eliminate one source of vehicle noise—the engine air intake system—AC Spark Plug Division builds air intake silencers, which usually are teamed with air cleaners in a variety of combinations. An intake silencer must be tuned to the specific engine on which it is to be used. Since tuning cannot be completed until a pre-production model of a new car is available for testing, the developmental time factor is critical. To save valuable hours of developmental time, AC Spark Plug has built a fully equipped mobile laboratory which allows AC engineers to perform the major part of the tuning operation directly at either the auto manufacturer's plant or field testing facility.

AIR INTAKE SILENCERS must be tuned to each make and model of automotive internal combustion engine and, sometimes, to each body style on which they will be used. This need for individual tuning is apparent when it is realized that the sound radiating from the carburetor air horn of the engine is dependent upon such factors as air consumption, number of cylinders, camshaft timing, intake valve cam lift rate, combustion-chamber pressure, intake manifold configuration, carburetor design, and engine speed. In addition, the original sound is modified further by the air cleaner, any other intake ducting, directional characteristics of the intake, engine compartment resonances, fire wall transmission loss, and body cavity resonances.

Over 70 varieties of engine intake silencers are used by the automotive industry. Standardization of silencer sizes and shapes is becoming increasingly difficult because of decreasing engine compartment space and the growing complexity of under-hood equipment.

3-Step Tuning Procedure Aided by Mobile Facility

The usual tuning procedure for an intake silencer, whose basic design is based on the vehicle manufacturer's specifications of space limitations and air cleaner requirements, involves recording and analyzing the character of objectionable noise; designing, building, and rough-tuning a sample silencer; and, finally, modifying the silencer design to make it suitable for a particular vehicle. This procedure involves considerable travel time and expense to and from the manufacturer's plant or testing facility. Since final tuning work cannot be done until all major modifications on the new engine are complete, delays due to traveling between the manufacturer's plant and the laboratory can mean a loss in developmental time in the critical period just prior to production. To alleviate the travel problem and provide quicker service, AC Spark Plug built a mobile laboratory, which is basically the shell of a custom-built house trailer (Fig. 1), to conduct tuning tests and make modifications in intake silencers directly at the manufacturer's plant or testing facility.

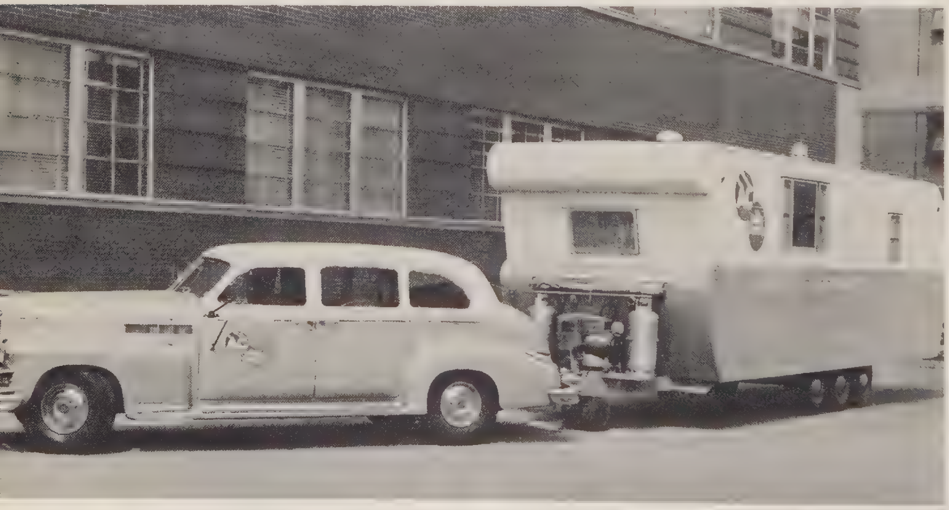


Fig. 1—The AC mobile laboratory and sound recording tow car facilitate on-the-spot development of air silencers at the automobile manufacturer's testing facility and eliminate much of the travel time normally required to and from the manufacturer's plant. The 31-ft long trailer houses complete engineering facilities for conducting air silencer tests in addition to a metal shop for fabricating test silencer assemblies. Mounted on the front end of the trailer is the electrical power generating plant and the propane gas tanks used to operate the plant. The tow car contains tape recording equipment for recording engine air intake noise and also serves as a towing dynamometer.

Acoustical tests performed in AC's mobile laboratory can be classified into 2 major groups: (a) determination of the objectionable frequencies of intake noise and (b) determination of the frequency response of experimental silencers.

Mobile Laboratory Measures Intake Noise

Tape recordings of engine air-intake noise are used to determine predominate frequencies (Fig. 2). The signals from these recordings, taken under various operating conditions, are fed through one channel of a 2-channel power amplifier to a loudspeaker. The signal from an audio oscillator is fed through the other channel of the amplifier to a second, identical loudspeaker mounted beside the first. The intensities of the 2 sounds are

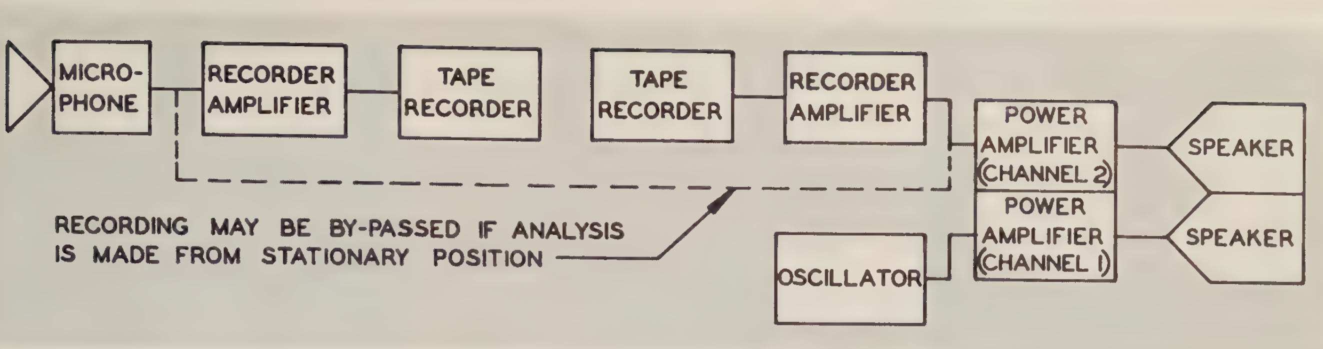

MICRO-PHONE
RECORDER AMPLIFIER
TAPE RECORDER
TAPE RECORDER
RECORDER AMPLIFIER
POWER AMPLIFIER (CHANNEL 2)
SPEAKER
POWER AMPLIFIER (CHANNEL 1)
SPEAKER
OSCILLATOR
RECORDING MAY BE BY-PASSED IF ANALYSIS IS MADE FROM STATIONARY POSITION

Fig. 2—The mobile laboratory is equipped with a system for making noise analyses. The recording setup minimizes the equipment in the sound recording tow car during a towing dynamometer run. The recorded electrical signal is fed through channel 2 of the power amplifier to a loudspeaker. A known-frequency sine-wave signal from an audio-frequency oscillator is fed through channel 1 of the power amplifier to a second speaker. After the intensities of the 2 sounds are equalized, the frequency of the oscillator is adjusted until it matches the harmonics of the intake noise, thus providing a qualitative analysis of the intake noise.

equalized, and the frequency of the oscillator is then adjusted until it matches the fundamental, or some harmonic, of the intake noise. The beat frequency between the 2 sounds is a guide to their difference. This test provides a qualitative analysis of intake noise. When the noise source is stationary, as when the engine is coupled to a dynamometer, the signal is fed directly from a microphone to the amplifier, thus by-passing the recorder stage.

Frequency Response of Silencer Measured

A system for acoustically driving an intake silencer and measuring its attenuation, or sound weakening power, is used to determine the frequency response characteristics of a silencer (Fig. 3). A known-frequency signal from an audio oscillator is fed directly (or through one channel of a power amplifier if a higher signal strength is necessary) to a special-purpose loudspeaker used as the silencer driver (Fig. 4). This unit has an "atmosphere-load" output of 115 db to 125 db (referred to 0.0002 microbar) from its 3-in. diameter orifice. The output is flat within ± 2 db from 70 cps to 700 cps. The driver is equipped with adapters so that any standard-carburetor silencer can be connected to its output. The sound that passes through the silencer is picked up by a condenser microphone and fed through a transformer, the second channel of the power amplifier, a passive band-pass filter to reduce background noises, and finally to a vacuum-tube voltmeter (VTVM). This meter then "reads" the relative sound pressure level at the microphone, or the absolute level if an acoustical calibrator is employed to calibrate the system.

To assure a constant-pressure sound input to the silencer, a second condenser microphone is mounted in the driver near the silencer entrance (carburetor connection). The sound, therefore, can be monitored as it enters the silencer.

The signal from the second microphone is fed through a microphone amplifier to a compressor (regulator) circuit of the oscillator. This circuit regulates the oscillator output to maintain the sound-pressure level constant at the monitoring microphone. Through this regulation, the "atmosphere-load" output of the driver can be improved to ± 1 db from 50 cps to 1,500 cps. Thus, a curve of VTVM readings against frequency will be a frequency response curve for constant pressure input. The silencer "tuning points," or maximum-attenuation frequencies, can be quickly ascertained by sweeping the oscillator frequency control and noting minimum meter readings.

Electronic Equipment Mounted On Compact Panel

In the mobile laboratory installation, a vibration-isolated rack cabinet (Fig. 5) is used to mount the oscillator, the 2-channel amplifier, the 2 speakers, a jack panel, and generating plant controls.

The inputs and outputs of all rack-mounted instruments, as well as 4 audio lines running to the sound room of the laboratory and 2 lines to the front of the trailer (outside), are connected to the jack panel. The panel instruments can be interconnected or connected to any remote plug by the use of patch cords. Double jack plugs allow reversal of polarity if needed. To minimize hum pickup through ground loops and other

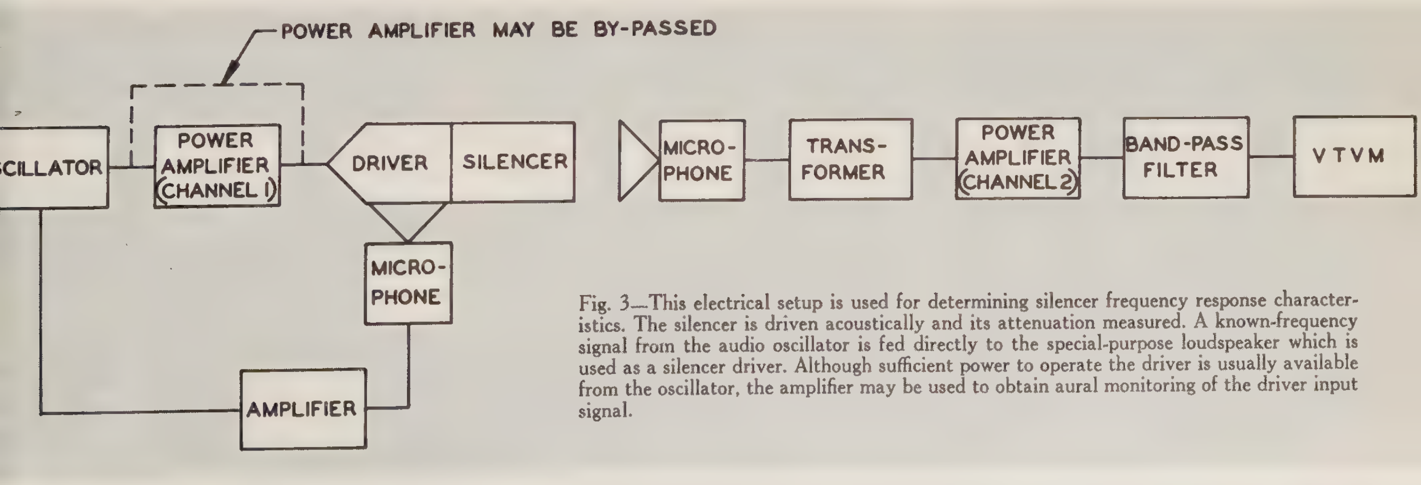

POWER AMPLIFIER MAY BE BY-PASSED
SCILLATOR
POWER AMPLIFIER (CHANNEL 1)
DRIVER
SILENCER
MICRO-PHONE
AMPLIFIER
MICRO-PHONE
TRANS-FORMER
POWER AMPLIFIER (CHANNEL 2)
BAND-PASS FILTER
VTVM

Fig. 3—This electrical setup is used for determining silencer frequency response characteristics. The silencer is driven acoustically and its attenuation measured. A known-frequency signal from the audio oscillator is fed directly to the special-purpose loudspeaker which is used as a silencer driver. Although sufficient power to operate the driver is usually available from the oscillator, the amplifier may be used to obtain aural monitoring of the driver input signal.

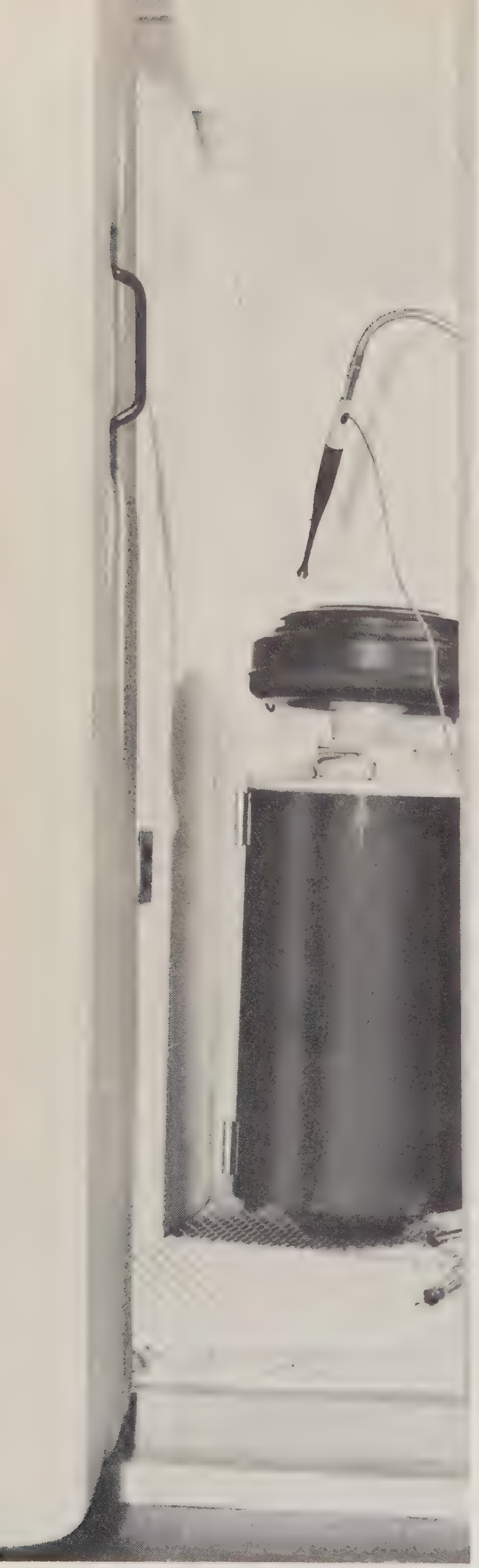


Fig. 4—An air silencer undergoing developmental tests is mounted on a special purpose loudspeaker, used as the silencer driver, located in the mobile laboratory's glass fiber lined sound room. The sound which passes through the silencer is picked up by the microphone positioned directly above the silencer. A second microphone, in a tube leading off the driver neck just below the silencer, is mounted at the entrance to the silencer to assure a constant-pressure sound input. The driver is equipped with adapters, which allow any standard silencer to be mounted to its output connection.

electrical noise, the patch cord shields are connected to the plug at one end only, and each jack is grounded to a heavy bus bar running through the rack cabinet and connected to the trailer and power ground. This shield-ground system is maintained in the audio cables between wall plugs and other instruments. Throughout the audio wiring, therefore, all cables are shielded, and these shields are grounded. No continuity between ground points through the shield is permitted.

The band-pass filter and VTVM are bracket-mounted on the side of the rack cabinet and furnished with cords to interconnect and tie into the jack panel. Standardized connectors for inputs and outputs are installed on instruments that are not rack-mounted to match the audio cables and wall plugs. The 2 outside plugs utilize AN connectors and cables for weatherproofing. All audio lines are run through flexible conduit for protection and additional shielding. The generating plant also is shielded.

Silencers Tested In Quiet Room

To provide a reasonably echo-free environment for testing silencers, a sound room is incorporated into the rear of the mobile laboratory trailer. This room is completely lined with 4-in. thick glass fiber panels covered with organdy. An expanded aluminum grating is used on the floor. The room provides a transmission loss from outside noise of 21 db to 25 db at 100 cycles and 41 db to 45 db at 400 cycles. Its reverberation time is less than 0.1 seconds.

Test Silencers Built in Mobile Metal Shop

Air cleaner and silencer assemblies are built almost entirely of sheet metal parts in the form of drawn plates and cups and lockseamed tubes and shells. To fabricate and modify these assemblies in the field, a small sheet metal shop is included in the mobile laboratory.

The shop contains benches on each side of the trailer on which are mounted equipment and tools for working with sheet metal and performing the lockseaming process on the tubes and shells. Wall-mounted cabinets and under-bench drawer space provide storage for hand tools and accessories for the required equipment. Ceiling-height steel cabinets contain complete silencer assemblies, sheet steel stock, a supply of standard-diameter tubes, portable sound equipment, and spare electronic parts.

Trailer Modified to Carry Equipment

To carry the heavy load of steel cabinets, benches, machines, tools, and electrical equipment, the frame depth of the mobile laboratory trailer was increased in the regions over the axles and at the tongue connection. Special running gear, consisting of 3 main axles and a 3-wheel full-castering dolly, was installed. Although load-equalizing hitches are preferred over dollies in most trailer hookups due to sway characteristics, a dolly, incorporating a shock absorbent spring system, was chosen in order that extra weight would not be added to the already overloaded (7,100 lb gross) tow car. Electric brakes on all 6 main wheels of the trailer are controlled manually or automatically from the tow car's hydraulic brake system.

The overall weight of the tow car and mobile laboratory trailer is about 17,000 lb. A hydraulic jack, placed under the trailer tongue, simplifies uncoupling from the tow car. The entire hitch load is placed on the dolly for parking.

A 3,500-watt electric generating plant is mounted on the trailer tongue to supply 115-v, 60-cycle, a-c power for lights, power tools, and instrumentation. Although the power plant is operated on propane gas supplied from 2, 40-lb tanks mounted on the front end of the trailer unit, it can, with some adjustments, be operated on gasoline, butane, or natural gas.

The electric power control panel includes a line voltmeter, a line frequency meter, and a running time meter for the generating plant. A 100-ft long extension cord, with adapters to fit the common types of outlets, is used when 115-v, 60-cycle power is available. A special connector is provided on the front of the trailer so that either the extension cord or the generating plant can be plugged into the trailer's electrical system. A connector also is provided at the front end of the trailer to tie into the towing car's 115-v electrical system when necessary.

Tow Car Has Dynamometer and Sound Recording Equipment

The tow car of the mobile laboratory is a modified 1949 limousine outfitted to make sound recordings and to function

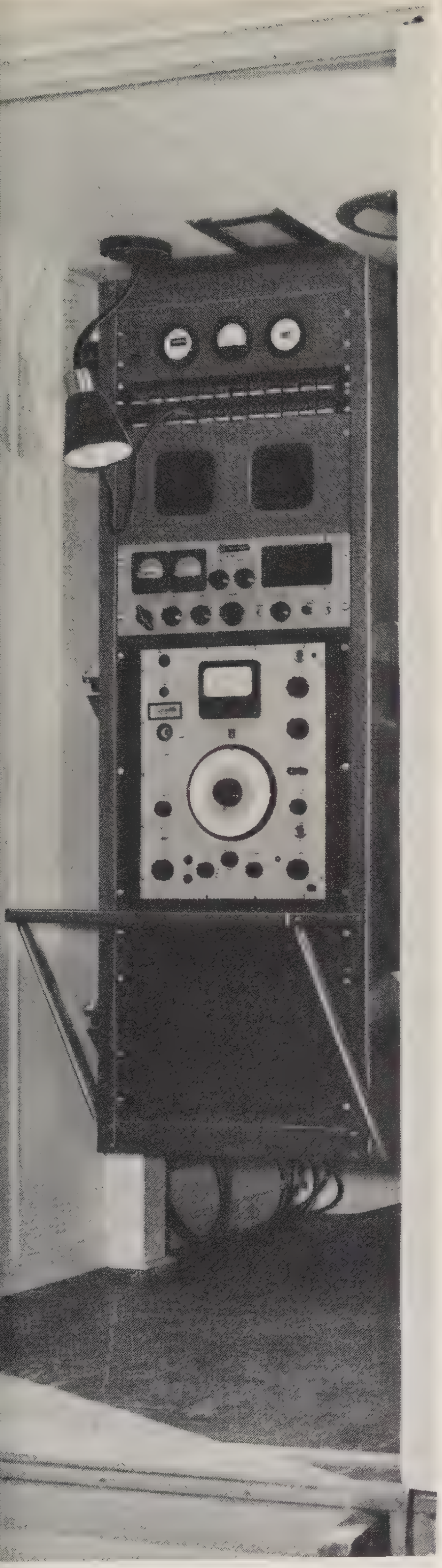


Fig. 5—The mobile laboratory's instrument panel is mounted in a vibration-isolated rack cabinet. From top to bottom the instruments are the power panel (generator controls and line meters), the patch panel, the twin speakers, the twin amplifier, and the oscillator. The filter and vacuum-tube voltmeter (VTVM), mounted to the right side of the cabinet, are not shown in this view.

as a towing dynamometer. In place of the rear seat is a vibration-isolated tape recorder and its accompanying amplifier. Provision also is made for an instrument panel and seating space for the equipment's operator.

To provide speed regulation and load control during towing tests, a magnetic eddy-current retarder dynamometer is mounted between the radiator core and grille of the tow car.

The dynamometer is driven from the front end of the engine crankshaft. The retarder, located directly in line with the crankshaft, is fastened to the chassis frame side-members and front cross-member. A flexible coupling and electric clutch are located in the drive shaft between the engine and retarder. The clutch allows the retarder to be disconnected for normal driving. A 24-v generator, with a special 300-v field, supplies current to the retarder. The generator is mounted above the retarder and is V-belt driven from it. To mount this equipment under the tow car's hood, the grille and bumper were moved forward 2 in., the radiator and fan were raised 7 in. to clear the drive shaft and components, and internal sheet metal modifications were made.

The dynamometer allows constant speed to be maintained, or acceleration and deceleration to be controlled, while tape recording air intake noise under actual road operating conditions. A test car can be operated at full throttle by using the sound recording tow car as a load vehicle, or it can be operated under motoring conditions by using the car as a tow vehicle. Thus, almost any possible condition involving throttle opening, vehicle speed, and ignition status can be duplicated for tape recording purposes. A solid bumper-attaching tow-bar, requiring no connection to vehicle steering or brakes, is used for safety.

Control of the dynamometer is through a thyratron circuit. Balancing voltage from a tachometer generator, mounted under the car and driven from the speedometer drive, and a manually controlled potentiometer actuate the circuit. The circuit output goes to the 24-v generator field and, thus, controls the output of the generator and retarder. The power required to rotate the generator also helps in the retarding action since it is driven from the same shaft. A duplicate speed control potentiometer is available for remote use in a test car.

A vibrator converter is installed in the trunk of the tow car to furnish power for the instruments and dynamometer control. The converter is a 375 v-amp capacity unit which takes 32-v d-c power from 6, 6-v, 200-amp storage batteries (also mounted in the trunk) and converts it to 115-v, 60-cycle sine-wave power. The converter has a stand-by vibrator that automatically takes over power supply in case of main vibrator failure.

Mounted in front of one of the former "jump seats" in the tow car is an instrument panel which contains:

- Power supply controls and monitoring meters
- Dynamometer controls (including speed control with motor-driven sweep), electric clutch control, and electric speedometer
- Firing frequency meter, or engine tachometer, for remote connection to test engine
- Plugs for 2 audio lines.

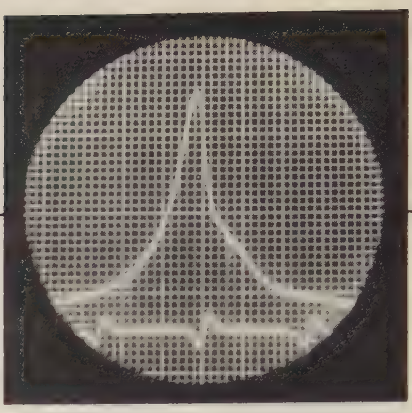
A small instrument panel mounted on the steering column of the tow car duplicates the clutch control, supplies an outlet for the remote speed-control box, and provides a mount for the retarder voltmeter.

Duplicate plugs are mounted on the hood and trunk lid for the remote speed-control, 115-v power, firing frequency meter and the 2 audio lines. One audio line is normally used for tape recording and the other for vehicle intercommunication with sound-powered headsets.

Conclusion

The AC mobile laboratory has already proven its value. On a pilot run to a vehicle manufacturer's proving ground, shop facilities in the trailer were used to make substantial modifications and completely assemble 2 engineering samples of a new silencer design. Since the trailer was parked at the test track, modifications were made and immediately tried on the test car. In this way the samples were delivered to the customer within 2 days after arrival of the mobile laboratory. Without the mobile laboratory, several trips of about 200 miles to and from the manufacturer's facilties would have been necessary. By providing facilities for on-the-spot tests, design, and modification of air intake silencers, the AC mobile laboratory decreases the time normally required for air silencer development.

Recording Instruments Aid Research Involving Measurement of Dynamic Phenomena



An increasingly large number of engineering measurements of rapidly varying phenomena are becoming necessary where visual observation is impossible or memory inadequate. In these cases dynamic measuring systems are used. At General Motors Research Staff, problems calling for the measurement of dynamic phenomena are under constant investigation. The instrumentation used for such measurements consists of 3 main components: a transducer, the matching network, and a recorder. Electrically actuated recorders are almost universally used, and the various types of recorders available for this work can be classified into 5 main categories. The engineer, therefore, bases the choice of recorder type to use on its operating characteristics and the application to which it will be put.

Many engineering measurements can be made by utilizing instrumentation which simply indicates the value of phenomena which are motionless or slowly changing. However, the dynamic measurement of rapidly varying phenomena is becoming increasingly necessary in research investigation, and most often a record must be obtained from which information subsequently can be "read off."

The gathering of information on dynamic phenomena affecting automotive components requires studies of dynamic measurements to determine the relationship of rapidly varying physical phenomena with respect to time, to obtain instantaneous comparisons between physical phenomena, to measure peak and/or minimum values, and to compare dynamic performance test units to a norm.

Typical dynamic measuring instrumentation consists of a transducer, the matching network, and a recorder (Fig. 1). While actuation of the recorder may be accomplished by means of direct-connected mechanical linkages or by pneumatic and hydraulic pressures, electrically actuated recorders are used almost universally. These recorders can be broken down into 5 specific categories: (a) self-balancing potentiometer, (b) high-speed pen motor recorder, (c) light beam oscillograph, (d) magnetic tape recorders, and (e) cathode ray oscilloscope. The following discussion will be confined to these 5 basic electrical recorders, their characteristics, and their applications.

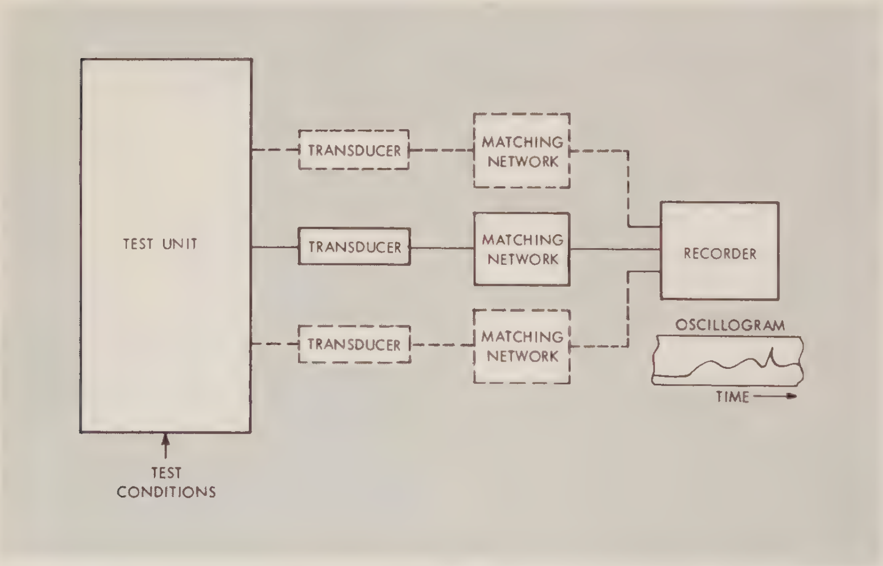


Fig. 1—This functional diagram shows a typical setup for a dynamic measuring system. The transducer provides a signal proportional to the physical event being measured. The matching network transforms the output signal from the transducer to a value sufficient to drive the recorder. The recorder converts the incoming signal to a record of the phenomena with respect to time. A wide range of transducers is available for measuring such items as temperature, pressure, speed, torque, displacement, sound, force, vibration, acceleration, flow, strain, and light.

Characteristics of Recorders Determine Their Job Applications

Recorders are selected for their ability to meet the requirements of the intended job application. Many factors influence recorder selection, but there are 5 primary characteristics common to all recorders. These are: frequency response, accuracy, form of presentation, number of channels, and sensitivity (Table I).

Frequency Response a Function of Stylus Mass

The most important characteristic of a recorder is its frequency response. In the pen, or stylus, type of recording instrument, the limit on upper frequency response is dependent upon the mass of the stylus and drive mechanism. Acceleration forces increase directly with deflection amplitude and as the square of the driving frequency. As the upper frequency limit is increased, the mass being driven must be reduced to keep the driving power within practical limits. This is appropriately illustrated in comparing the self-balancing potentiometer, the high-speed pen motor recorder, and the light beam oscillograph with stylus masses of approximately 300 grams, 7 grams, and 0.01 grams, respectively. High-frequency response of the cathode

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A survey of recorders as engineering tools for dynamic measurement

ray oscilloscope is directly due to the infinitesimal mass of the electron beam.

Complex wave shapes containing many harmonic components are typical of the data obtained in industrial recording. The frequency response band of the recorder should be such that all harmonic components will be reproduced faithfully. In selecting a recorder for handling complex wave shapes, the upper limit of the frequency response band should be specified at 10 times the fundamental frequency being recorded.

Accuracy Necessary for Qualitative Measurement

Recorder accuracy is affected by linearity, stability, repeatability, and resolution. Though non-linearity can be taken into account by use of a calibration curve, data reduction is greatly simplified if a fixed-calibration constant is applied (linear calibration). Zero drift and span calibration changes will result if a recorder possesses poor stability. In modern recorders, repeatability usually is not a serious problem and need be considered only when very close measurements are required. Resolution is a function of the maximum possible deflection and trace width. With present-day recorders, the trace width is such that, by careful examination of the recordings, a resolution of about 0.02 in. of deflection can be obtained.

Form of Data Presentation Desired Depends on the Application

In chart-type recorders, direct writing is the most desirable form of presentation because it allows immediate use of the data. The main advantages of the systems using photographic recording paper are the faster writing speeds possible for recording high-frequency phenomena and the fact that full chart width is available to each channel on multi-channel recording. Visual presentation can be used for observing repetitive-type data on either the oscillograph or oscilloscope. The magnetic tape recorder presents data in electrical form suitable for additional processing into a variety of end instruments, such as frequency spectrum analyzers, recorders, and analog computers.

Number of Channels Determines Versatility

The number of channels available on a recorder is important from the standpoint that recorder versatility is increased by additional channels. The number may vary from 1 channel on a self-balancing potentiometer to as many as 70 channels on a light beam oscillograph.

Sensitivity May Be Increased by Amplifiers

Sensitivity is not a real problem because a 0 mv to 5 mv span can be obtained readily on all recorders either through basic recorder sensitivity (built-in sensitivity) or by the use of accessory amplifiers. However, great simplification of equipment in multi-channel recording applications results when recorders with high basic sensitivities are used.

Self-Balancing Potentiometer Capable of High Accuracy

A self-balancing instrument is inherently capable of producing high accuracy.

RECORDER CHARACTERISTICS

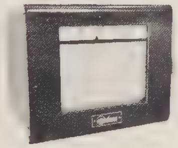
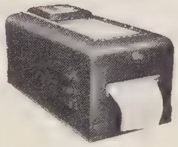
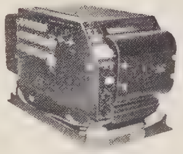
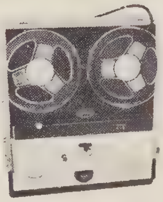
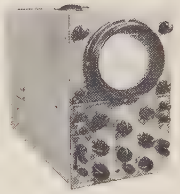
	 SELF BALANCING POTENTIOMETER	 HI-SPEED PEN MOTOR RECORDER	 LIGHT-BEAM OSCILLOGRAPH	 MAGNETIC TAPE RECORDER	 CATHODE-RAY OSCILLOSCOPE
FREQUENCY RESPONSE	1.0 CPS	100 CPS	3 Kc	10 Kc	1.0 Mc
ACCURACY	0.5%	5%	2%	2%	5%
PRESENTATION	Direct Writing	Direct Writing	Indirect Writing	Electrical	Visual
NUMBER OF CHANNELS	1	1 to 6	1 to 70	1 to 14	1 to 2

Table 1—The 5 main types of recorders pictured here are compared for their characteristics of frequency response, accuracy, form of presentation, and number of channels. Recorder sensitivities are not directly comparable due to the availability of accessory amplifiers to handle low-level signals.

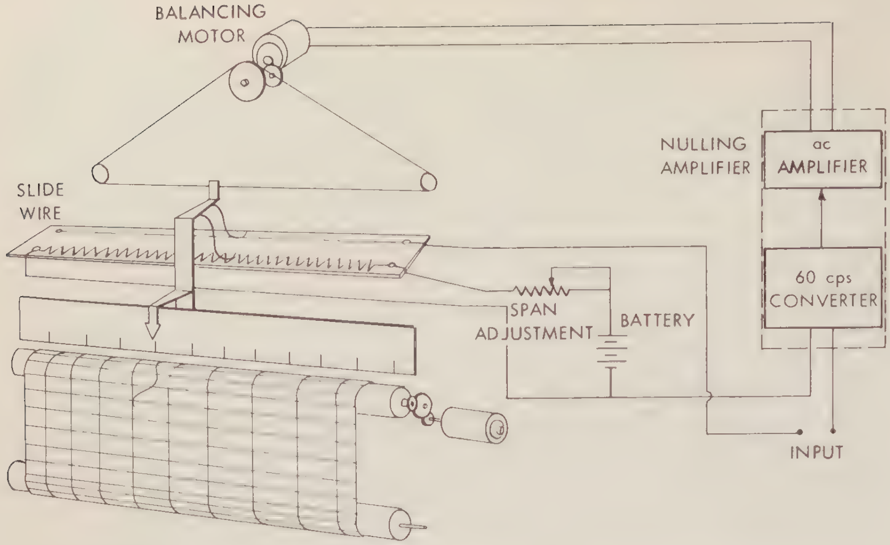
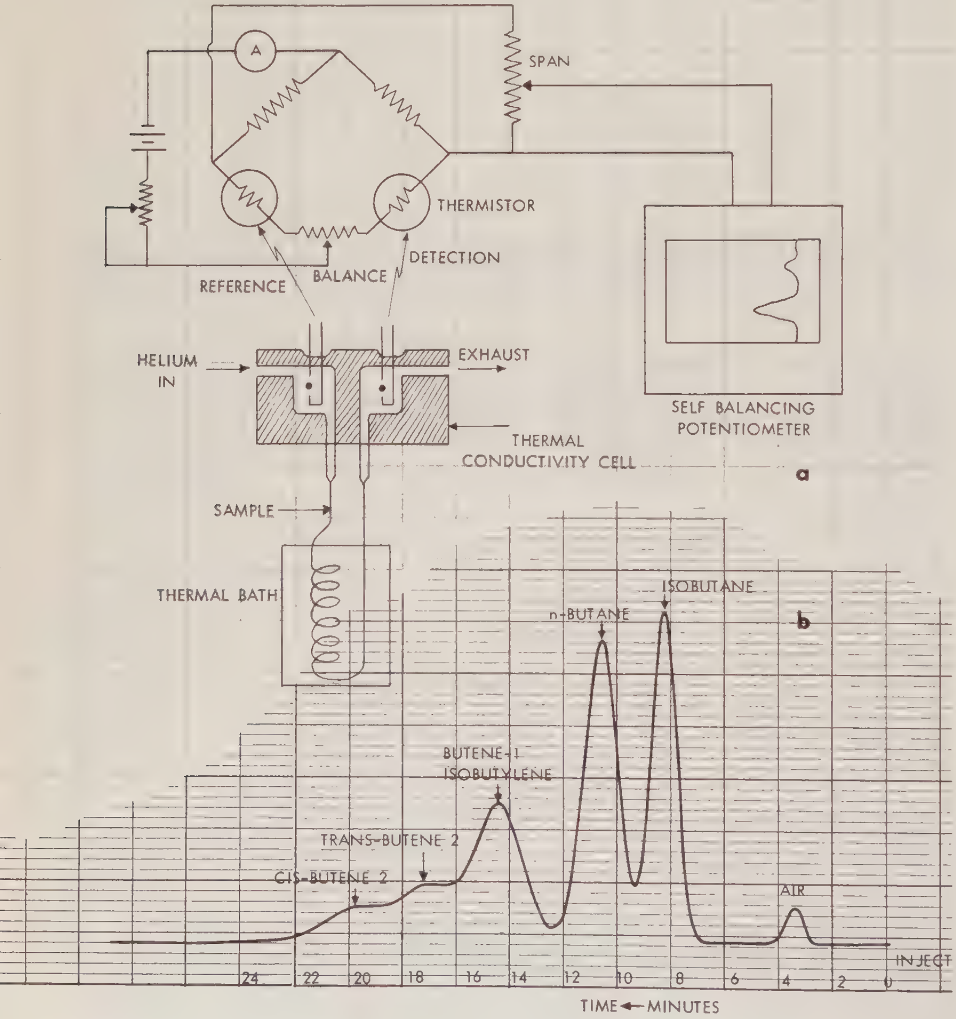


Fig. 2—In the basic scheme of the self-balancing potentiometer, the input signal voltage to the recorder is compared against the slide wire voltage. The difference, or error, voltage is applied to a nulling amplifier which drives a balancing motor. The motor repositions the slider to tap off a voltage equal to the input. Time base is obtained by constant-speed driving of the chart paper.



The 0.5 per cent accuracy typical of the self-balancing potentiometer (Fig. 2) is obtained by using a standard cell reference voltage and a high gain amplifier (typical gain from 10^6 to 40×10^6) to obtain a high motor torque versus input error voltage relationship. Transient response of 1 sec for full-scale deflection is obtainable; however, the very latest types of this recorder advertise a 0.25 sec response time.

Most self-balancing potentiometer recorders employ a direct writing presentation on 10-in. wide chart paper at chart speeds between 2 in. per hr and 480 in. per hr. Two-channel offset pen and multichannel sequential printing units also are available. Basic sensitivity of these units is high with a minimum span from 0 mv to 1 mv d-c available.

A typical application of the self-balancing potentiometer is in gas chromotography, an analytical method for the qualitative and quantitative determination of the composition of gases and volatile liquids boiling up to 300° C (Fig. 3). This analytical method is used for fuel composition and exhaust gas studies to obtain better understanding of engine combustion performance as related to fuel composition. Other potentiometer applications have been in brake dynamometer torque measurement, monitoring and controlling temperature of heat treat furnaces, and gas turbine component testing.

High-Speed Pen Motor Recorder Presents Qualitative Picture

The high-speed pen motor recorder (Fig. 4) features direct presentation of events in the frequency band from 0 cps to 100 cps. Accuracy is on the order of 5 per cent. Resolution is poor due to the narrow deflection obtainable (±0.5 in. at 100 cps). Inking problems are eliminated by the use of an electric stylus and a voltage-sensitive paper or a heated stylus and heat-sensitive paper. Up to 6 pen motors may be mounted side by side

Fig. 3 (left)—One application of the self-balancing potentiometer is in determining the composition of gases and volatile liquids by the gas chromotography method (a). The helium gas passes over a reference thermistor and enters the thermal bath. Sample gas is injected and carried by the helium through the thermal bath, where decomposition takes place. Helium and sample gas composition products then pass over the detector thermistor, producing bridge unbalances caused by changes in thermal conductivity. The record produced (b) shows a gas mixture of butane and C4 isomers. Identification of the gas composition products is made by their position on the time axis.

to provide multi-channel operation. Chart speeds from ½ in. per hr to 10 in. per sec are available. A major shortcoming is that the driving power requirements are high, 30 mils into a 1,500-ohm coil being a typical value. This necessitates the use of an amplifier to obtain high sensitivities.

The high-speed pen motor recorder has its greatest value where a qualitative picture is required. A typical application is for testing hydraulic starter motors for Diesel engines (Fig. 5), where the resultant data are used to evaluate design changes. Other applications have been made to clutch plate studies, metallurgical investigations, and compressor surge and stall studies.

Light Beam Oscillograph May Incorporate Up to 70 Channels

The heart of a light beam oscillograph (Fig. 6) is a mirror-type galvanometer. Frequency response to 3,000 cps can be obtained using amplifiers; however, it is best to utilize a galvanometer having the lowest applicable natural frequency since sensitivity and natural frequency are inversely related. Amplitude accuracy of 2 per cent can be maintained with careful calibration techniques. The galvanometer is linear within ±1 per cent over a deflection range of ±2 in. It also is extremely stable with respect to temperature changes and aging.

Many oscillograph models are available, ranging from 6 channels to 70 channels. The light beams can be criss-crossed without interaction, thus allowing the traces to be superimposed and making available the total chart width deflection for each channel. Chart papers vary from 2 in. to 12 in. in width. Variable chart

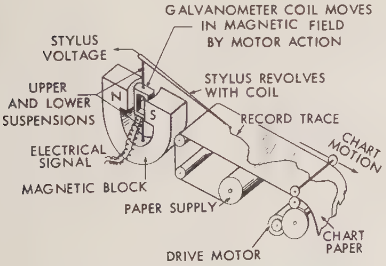

GALVANOMETER COIL MOVES IN MAGNETIC FIELD BY MOTOR ACTION
STYLUS VOLTAGE
UPPER AND LOWER SUSPENSIONS
N
S
STYLUS REVOLVES WITH COIL
RECORD TRACE
CHART MOTION
ELECTRICAL SIGNAL
MAGNETIC BLOCK
PAPER SUPPLY
CHART PAPER
DRIVE MOTOR

Fig. 4—This schematic drawing illustrates the operation of a high-speed pen motor recorder. The galvanometer coil is driven in response to input current. Motor action causes the coil to revolve, and turning torque is balanced by a restraining torque set up by the upper and lower suspension springs. The stylus turns with the coil, tracing signal variations on the chart paper.

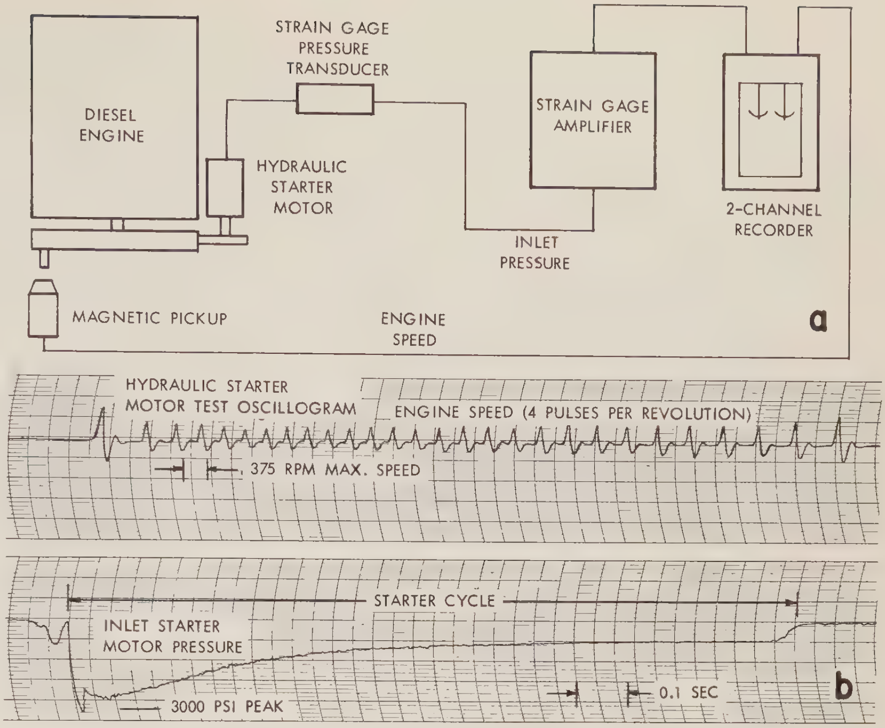


Fig. 5—The high-speed pen motor recorder is utilized in instrumentation for testing Diesel engine hydraulic starter motors (a). The chart (b) shows the instantaneous measurements obtained to determine maximum engine speed and peak inlet pressure to the starter motor.

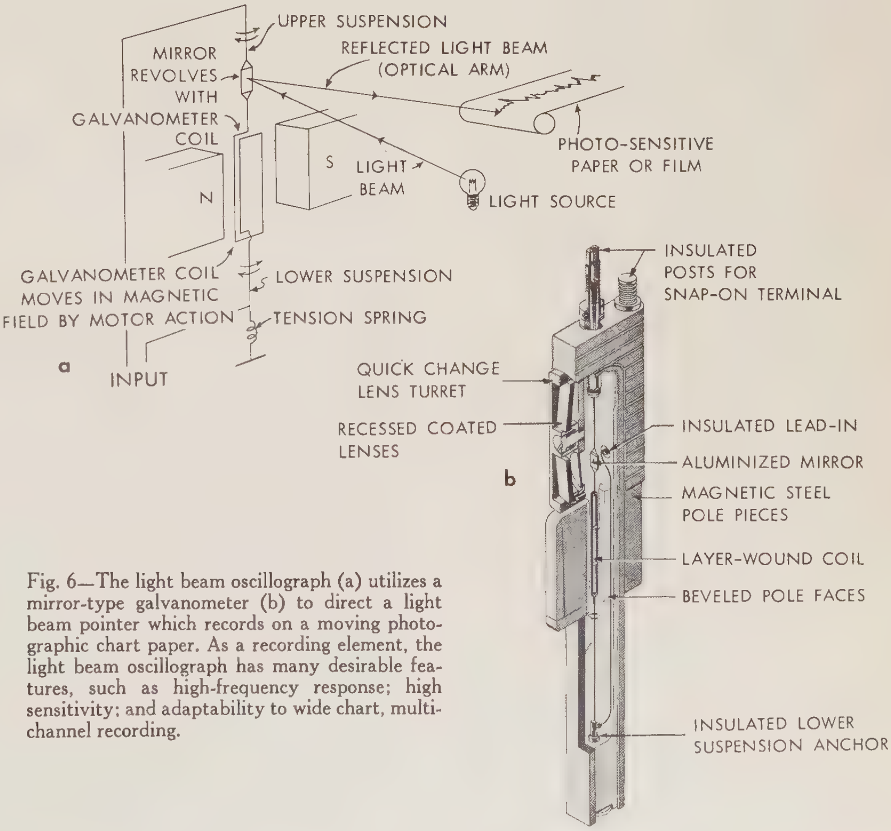

UPPER SUSPENSION
REFLECTED LIGHT BEAM (OPTICAL ARM)
MIRROR REVOLVES WITH GALVANOMETER COIL
S
N
LIGHT BEAM
PHOTO-SENSITIVE PAPER OR FILM
LIGHT SOURCE
GALVANOMETER COIL MOVES IN MAGNETIC FIELD BY MOTOR ACTION
LOWER SUSPENSION
TENSION SPRING
a
INPUT
INSULATED POSTS FOR SNAP-ON TERMINAL
QUICK CHANGE LENS TURRET
RECESSED COATED LENSES
b
INSULATED LEAD-IN
ALUMINIZED MIRROR
MAGNETIC STEEL POLE PIECES
LAYER-WOUND COIL
BEVELED POLE FACES
INSULATED LOWER SUSPENSION ANCHOR

Fig. 6—The light beam oscillograph (a) utilizes a mirror-type galvanometer (b) to direct a light beam pointer which records on a moving photographic chart paper. As a recording element, the light beam oscillograph has many desirable features, such as high-frequency response; high sensitivity; and adaptability to wide chart, multichannel recording.

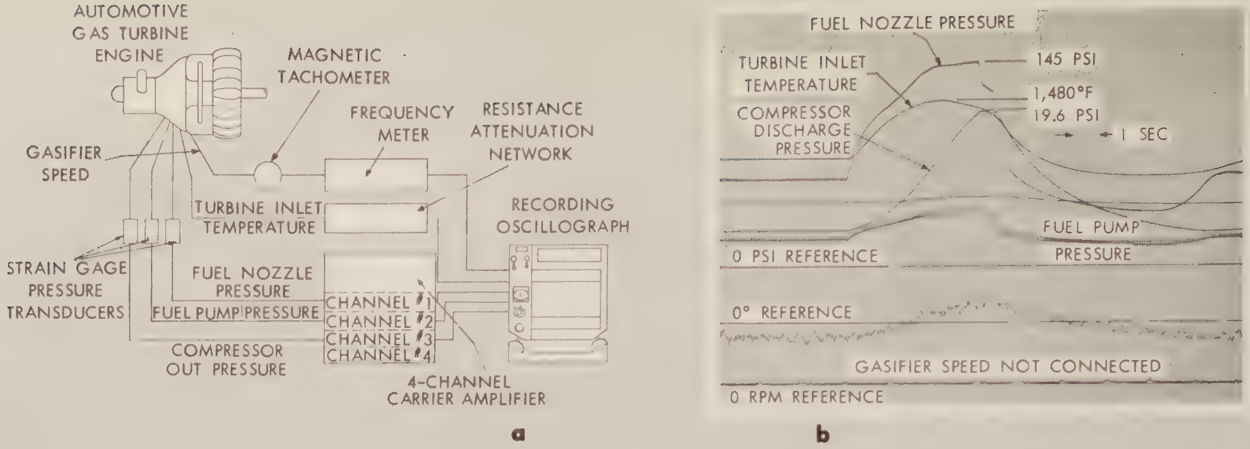


Fig. 7—The light beam oscillograph is used in instrumentation for testing automotive gas turbine engines (a). In this specific setup, gasifier speed and turbine inlet temperature measurements were simplified by using high-sensitivity galvanometers, eliminating the need for amplifiers. Vertical bars on the record (b) are simultaneously recorded timing lines spaced 0.1 sec apart. Breaks in the data traces are for trace identification.

speeds from ¼ in. per sec to 115 in. per sec are generally provided. Galvanometers of high sensitivity—5 micro amp per in. deflection—and low frequency—0 cps to 30 cps—often are sufficiently sensitive to allow direct connection to the transducer, resulting in tremendous simplification.

A typical application of a light beam oscillograph is in the testing of automotive gas turbine engines (Fig. 7). Other applications have been dynamic studies of pistons and piston ring behavior; investigation of stress conditions caused by transient temperature differentials; and vibration studies of automobile components, such as ball-joint steering, suspensions, and clutch plates.

Magnetic Tape Recorders Store Data for Later Processing

The magnetic tape recorder is a new instrumentation tool. The tape recorder does not provide a written record; its usefulness lies in the ability to store data in magnetic form and to reproduce it repeatedly in electrical form for further processing. The familiar audio tape recorder, though useful for sound studies and certain vibration studies, cannot be used where accurate amplitude reproduction of data is required. To accomplish accurate amplitude recording a new type of recorder, referred to as an instrumentation tape recorder, has been developed.

The main difference between the instrumentation and audio types of magnetic tape recorders is in the recording technique used to store the information on tape. The audio recorder uses a direct recording technique where the magnetic flux density of the tape is directly propor-

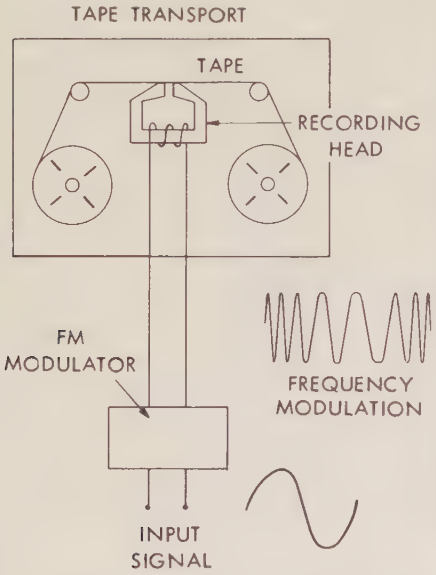


Fig. 8—The instrumentation tape recorder utilizes frequency modulation techniques to put data on tape. The data signal, in the form of d-c voltage, controls the output frequency of an FM modulator; this frequency is recorded on the tape. On the play-back, the frequency is detected by an FM discriminator and converted back to d-c voltage.

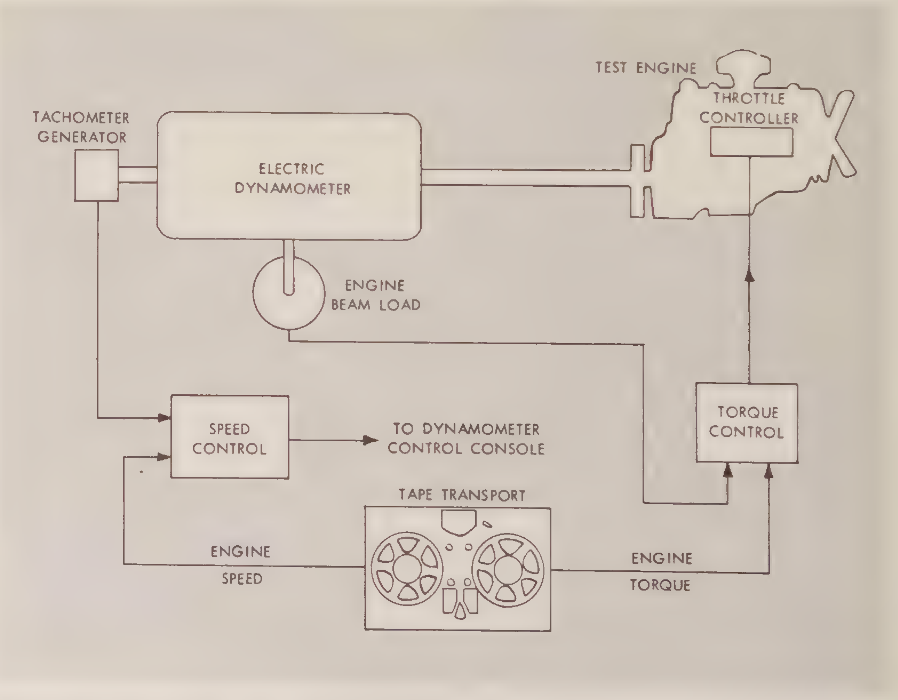


Fig. 9—Dynamometer programming is one application of the instrumentation tape recorder. The dynamometer subjects the engine to speed and torque conditions which have been recorded previously on tape in actual traffic situations.

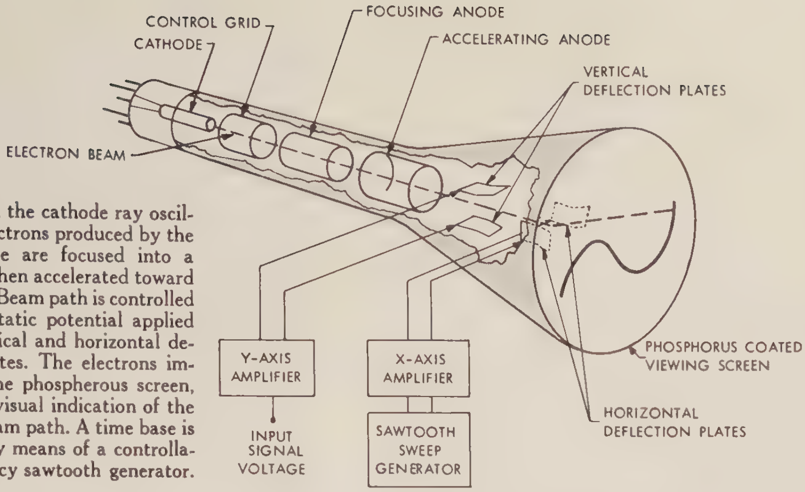


Fig. 10—In the cathode ray oscilloscope, electrons produced by the hot cathode are focused into a beam and then accelerated toward the screen. Beam path is controlled by electrostatic potential applied to the vertical and horizontal deflection plates. The electrons impinge on the phospherous screen, producing visual indication of the electron beam path. A time base is provided by means of a controllable frequency sawtooth generator.

tional to signal amplitude. Due to non-linear magnetic characteristics and variations in magnetic media density, poor amplitude accuracy results. The recording of static levels is impossible, also. The instrumentation tape recorder, on the other hand, uses frequency modulation techniques (wide band FM) to put the data on tape (Fig. 8).

The Research Staff uses an instrumentation tape recorder unit having the following specifications:

- Frequency response—0 cps to 10,000 cps at 60 in. per sec tape speed; frequency response decreases proportionally at lower tape speeds
- Amplitude accuracy—2 per cent
- Number of channels—14 wide band FM channels; additional channels are provided through multiplexing but with sacrifice in upper frequency response
- Sensitivity—0 volt to 1.0 volt rms across 100,000 ohm; accessory amplifiers are required when used with a strain gauge, thermocouple, and other low-output level transducers
- Tape speeds—1⅞, 3¾, 7½, 15, 30, and 60 in. per sec; recording can be done at one speed and playback at a different speed to provide time-base expansion or compression.

An application of an instrumentation tape recorder is in programming engine and chassis dynamometers (Fig. 9).

Cathode Ray Oscilloscope Most Versatile of Recorders

The operation of the cathode ray oscilloscope is based on the cathode ray tube (Fig. 10). Frequency response of the cathode ray tube is extremely high due to the infinitesimal mass of the electron beam. The amplifier required to raise the input signal to a level sufficient to drive the deflection plates is the limiting factor affecting frequency response. Present-day oscilloscopes using high gain amplifiers have a frequency response of from 0 megacycle to 1 megacycle. Accuracy is approximately 5 per cent. Visual presentation of repetitive signals is adequate for all frequencies above approximately 10 cps and can be extended down to 1 cps by the use of high-persistant phospherous screens. Transient phenomenon can be recorded using photographic techniques. The oscilloscope is limited as applied to multi-channel recording, and complex switching electronics is required when more than 2 channels of data are to be recorded. Common oscilloscope sensitivity is 7 mv per in.

The cathode ray oscilloscope is the most versatile of all recorders. It is an excellent tool for obtaining qualitative information of repetitive signals and high-frequency transients. It can be converted easily to an XY indicator or recorder to obtain instantaneous phase relationships and function plots, such as Lissajous figures. A typical application is the recording of pressure-time cards of an internal combustion engine (Fig. 11). The oscilloscope also is applied to compressor surge and stall studies, spark ignition investigations, and hydraulic pump noise and pressure pulsation analyses.

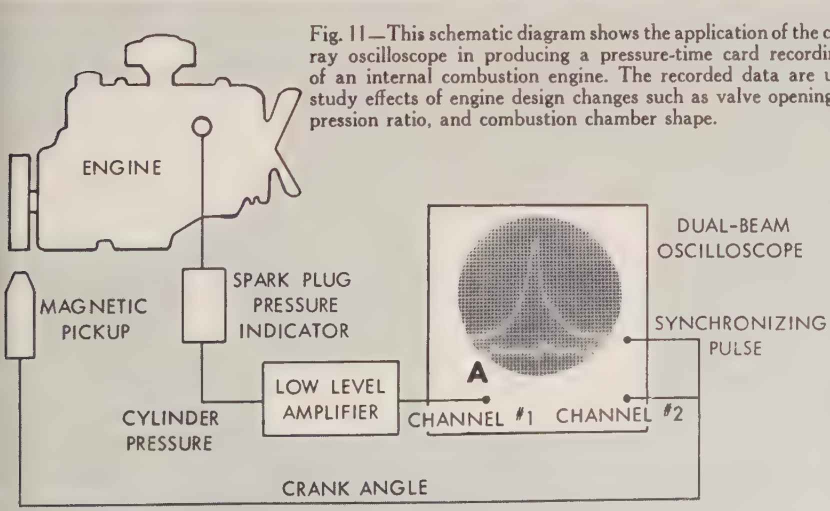


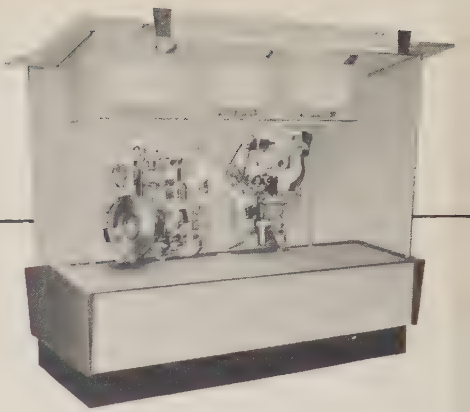
Fig. 11—This schematic diagram shows the application of the cathode ray oscilloscope in producing a pressure-time card recording (*A*) of an internal combustion engine. The recorded data are used to study effects of engine design changes such as valve opening, compression ratio, and combustion chamber shape.

Summary

The advantages for measurement of dynamic phenomena offered by each of the 5 main types of recording instruments makes it possible to select a recorder which will be most applicable to specific instrumentation problems. The self-balancing potentiometer gives highly accurate results, while the high-speed pen motor recorder is most useful in studies where a qualitative analysis is desired. The light beam oscillograph presents advantages for multi-channel recording. The instrumentation tape recorder is capable of storing data and reproducing it for subsequent processing. The cathode ray oscilloscope is useful in obtaining qualitative information of repetitive signals and high-frequency transients and can be converted to an XY indicator.

The engineer who is familiar with the operating principles of these 5 basic types of recorders can evaluate their capabilities and choose the one which will be of best aid in a particular instrumentation problem.

How a Cutaway Exhibit Was Built to Show the Operation of a 2-Cycle Diesel Engine



The cutaway, or sectioned, exhibit is a widely used method for displaying the inner construction and operating principles of a complex mechanism. Recently, Detroit Diesel Engine Division engineers undertook the design of a cutaway exhibit for a 3-cylinder, Series 71 Diesel engine for the purpose of informing the general public on the operating principles and construction of a 2-cycle Diesel engine. The complexity of the engine posed 3 major problems to the engineers designing the exhibit: (1) how should the engine, its component parts, and lubrication and engine coolant passageways be sectioned to provide maximum visualization and comprehension, (2) how should the exhibit be displayed so that all sectioned components and construction details will be easily observed when viewed from one direction, and (3) how should the overall exhibit be designed to obtain maximum ease in maintenance? The solution to these problems resulted in a novel exhibit in which sectioned halves of the engine move transversely apart, oscillate simultaneously, and then return to a closed position. The oscillating exhibit permits complete observation of all inner and outer details of both halves of the sectioned engine from one vantage point.

THE USE of the Diesel engine in equipment for transportation, construction, farming, and industrial applications has increased significantly in recent years. Contributing to these needs, Detroit Diesel Engine Division had produced by 1956 a total of 60-million hp in its Series 71 engine. This engine is a 2-cycle, high-speed design available in 3-, 4-, and 6-cylinder, single and multiple engine units to meet the user's requirements. Although the Series 71 engine's cylinder displacement of 71 cu in. has remained constant since 1939, the brake horsepower rating has increased during the same period—a 6-cylinder model, for example, increasing from 165 bhp to 244 bhp.

As the growing use of these engines brought them to the attention of more and more people, a natural result was increased public interest in the 2-cycle Diesel engine. Detroit Diesel Engine Division decided, therefore, that along side of engineering design work should be placed the corollary job of informing the general public about the 2-cycle engine.

To accomplish this objective it was decided to build an exhibit of a cutaway, or sectioned, working engine which would reveal the internal features and illustrate the operating principles of the 2-cycle engine. A number of techniques for building cutaway models were considered, and it was decided that a 3-cylinder, Series 71 RD Fan-to-Flywheel type Diesel engine would best fit the proposed display for the following reasons:

- Three cylinders would be needed to demonstrate all typical sections of the Series 71 engine
- The number of parts in the Series 71, 3-cylinder engine are at a minimum, thus avoiding confusion to the viewer of the display because of repeated cutaway parts
- The weight of the engine is low which would aid in smooth operation of the animated exhibit and also permit easy handling and packaging for shipment
- The 3-cylinder arrangement would point up the distinctive features of a 2-cycle Diesel engine and demonstrate how a 6-cylinder, 4-cycle engine is reduced to a 3-cylinder, 2-cycle engine by replacing 3 cylinders of the 4-cycle engine with a scavenging-air blower
- The distinctive design feature of the Series 71 engine, in which both the engine cylinder block and cylinder head are symmetrical at both ends and may be reversed either separately or together with respect to the crankshaft, would enable a choice as to the best display location for the blower, manifold, and auxiliaries which, in an actual engine, may be located on either side of the engine to suit the user's requirements.

Cutaway Engine Details

One of the most effective ways to show visually the inner construction details and components of a mechanism is to cut the mechanism into 2 parts. If the mechanism is not too complicated, a single, continuous cutting plane, taken on the main axis or centerline, can be used. If the mechanism is more complicated, the cutting plane must be offset and have changes in direction which go through details not on the main axis or centerline in order to show inner construction details to the best advantage.

When initial planning was undertaken regarding the selection of cutting planes needed to section the 3-cylinder, Series 71 engine, it was realized that the number of sectioned components would tend to become somewhat confusing when viewed by someone not familiar with the details of a Diesel engine's inner construction. It was decided, therefore, to keep the number of repeated sectioned parts to a minimum and to use cutting planes which would section the engine into 2 halves (Fig. 1) in such a manner that the lubrication and engine coolant passageways would have the least amount of interruption throughout their course. This sectioning method automatically made the lubrication and engine coolant passageways continuous in both halves of the engine. The passageways, thus, were easy to identify thereby making the engine more useful for illustrating operating principles.

It was decided that all auxiliary and control units and external connections would be placed on the right-hand side of the engine (when viewed from the flywheel end) with the exception of the cranking motor, which would be placed on the left side for the purpose of driving the crankshaft to animate that half of the exhibit.

By ALBERT DeFEZZY
and GEORGE P. HANLEY
Detroit Diesel Engine Division

Three considerations: cutting planes, method of display, and ease of maintenance

For each component part sectioned it was necessary to use 2 such parts because approximately half of each part was reduced to chips during the sectioning process, which was accomplished by an end mill.

The 2 sectioned halves of the engine are referred to as the *principle*, or left, half which primarily illustrates the principles of operation (Fig. 2) and the *auxiliary*, or right, half which illustrates the function of the engine's auxiliary equipment (Fig. 3).

Principle Half of Cutaway Engine

The principle half of the cutaway engine displays such fundamental power production components as the crankshaft, flywheel, connecting rods, valve mechanism, oil pump, and fuel injectors, in addition to lubrication and engine coolant passageways.

The principle half of the engine is sectioned on the centerline of the crankshaft at the number 3 main bearing and longitudinally from there to the rear end (flywheel end) of the engine. This permits observation of the number 3 main bearing oil-feed gallery (which is the same for all bearings) and the crankshaft passages which register with this gallery to supply oil to the number 3 connecting-rod bearing. The number 3 connecting rod, in turn, is quarter-sectioned throughout its length to show the vertical, drilled passages which carry oil to lubricate the piston-pin bushing and cool the underside of the piston crown. At the top of the connecting rod is a spray nozzle used to distribute oil over the crown of the piston for the purpose of conducting heat away from the piston.

The principle half of the engine also displays the unique method for gasketing the head-block joint to seal compression. Individual, laminated steel compression gaskets are used at each cylinder between the cylinder head and the top of the cylinder block. The entire load of the cylinder head bolts is applied to these gaskets, which are shown in section at the number 3 cylinder. This method of gasketing results in satisfactory and durable sealing of high cylinder-gas pressures resulting from the use of a 17 to 1 compression ratio.

The principle half of the engine also displays the method used for carrying water and oil passages across the head-block joint by the use of rectangularly sectioned rubber rings. The compressive force required to accomplish this sealing is a negligible subtraction from the total head-bolt force. One of the rectangularly sectioned rubber rings is displayed directly below the water nozzle adjacent to the exhaust-valve seats between the number 1 and number 2 cylinders.

Auxiliary Half of the Engine

The auxiliary half of the engine displays all auxiliary and control units, such as the air blower, water pump, fuel pump, generator, and engine-speed governor with its associated linkage to the fuel injectors. This sectioned half of the engine also displays the various manifolds and galleries.

The water pump is driven by the lower rotor shaft of the positive-type blower. This blower, which has 2 hollow 3-lobe rotors, supplies both scavenging air to expel burned gases out of the cylinders through the exhaust-valve ports and clean air for efficient combustion and cooling of internal engine parts, especially the exhaust valves. (The cylinder of a 2-cycle engine is filled with fresh air, whereas the 4-cycle engine cylinder air charge is diluted with exhaust from the clearance volume.) The lobes of the blower are partially displayed through a blower-discharge opening in the air-box wall for the number 2 cylinder. The air-box is an air chamber which surrounds the water jackets in the same manner that these jackets surround the engine block and cylinder head.

Also displayed in the auxiliary half, just below the top of the cylinder block, is the balancer shaft which parallels the camshaft. The balancer shaft is necessary in a 3-cylinder, 2-cycle Diesel engine due to elimination of the first 3 cylinders of a 6-cylinder, 4-cycle engine. The reciprocating masses of the 2-cycle engine produce an unbalanced couple which tends to rock the engine from end to end. This unbalanced couple is balanced by an arrangement of rotating counterweights mounted at both the front and rear ends of the balancer shaft and camshaft. The counterweights produce a couple equal and opposite in magnitude to the unbalanced couple produced by the reciprocating masses. The counterweights at the front ends of both the balancer shaft and camshaft produce a vertical force analogous to the number 1 piston of a 6-cylinder, 4-cycle engine.

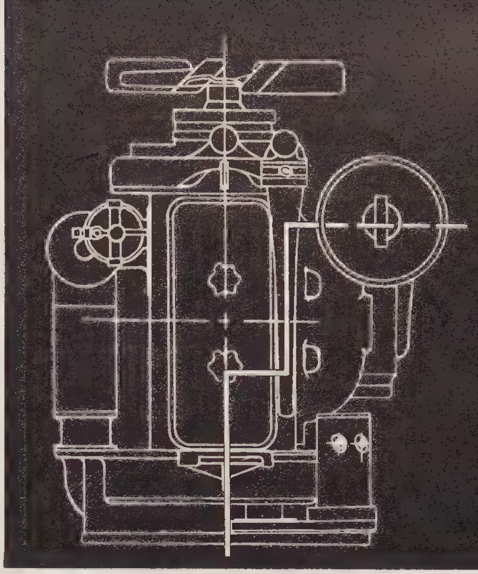


Fig. 1—The cutting planes used to section the display engine were carefully selected so that all inner components of both halves of the engine would be presented in the clearest possible manner.

The display engine has a limiting speed, single weight, mechanical governor which controls the idling speed of the engine and limits its maximum operating speed. The governor flyweight assembly is driven from the front end of the upper rotor shaft of the blower. This assembly actuates a vertical shaft connected through a differential lever and link to the fuel-injector control tube mounted on top of the cylinder head. The adjustable levers have "feet" which engage the fuel-injector racks. Manual control is applied to the differential lever through an external throttle-control lever mounted on top of the engine-speed governor. This control is visible directly beneath the thermostat of the engine cooling system.

Animation

Both halves of the cutaway engine are animated when in the closed position and when completely apart. The auxil-

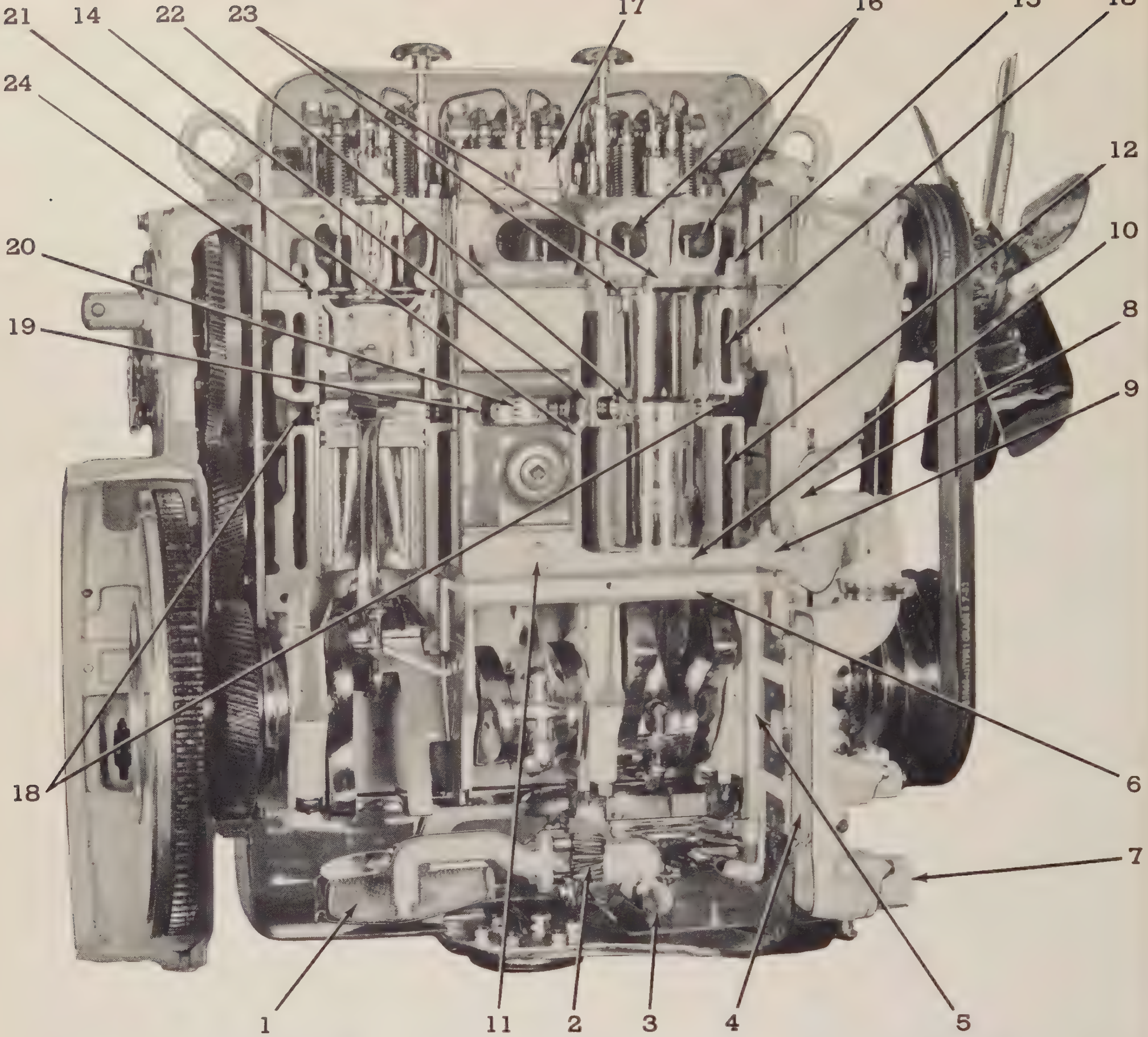


Fig. 2—The *principle* half of the cutaway 3-cylinder engine primarily illustrates the operating principles and displays such fundamental components as the crankshaft, flywheel, connecting rods, pistons, valve mechanisms, and fuel injectors. It also displays the lubrication system and the engine coolant passageways. The lubrication gallery starts at the oil-pump inlet screen (1) located in the oil-pan sump and moves upward and to the right through the helical gears of the oil pump (2), past a transverse relief valve (3), and then upward into the block. Almost immediately after entering the block, the gallery turns outward to enter the oil cooler (4) mounted on the front-right lower corner of the block. The gallery then passes upward through the oil cooler and returns to the block through a "T" where the oil flow is divided: part flowing downward (5) to a pressure regulating dump valve, located on the pan rail above the oil sump, and part forced upward to the main longitudinal distribution gallery (6) which runs to the left toward the flywheel end of the engine. Leading from the main distribution gallery are small-diameter transverse passages which connect with vertical passages to feed lubricant downward to each main bearing.

The path of the engine coolant flow begins at the radiator hose connection (7) to the oil cooler. From this point the coolant flows upward through the oil cooler to the water pump scroll (8) and then into the water-inlet manifold (9) which is integral with the block and runs directly above the longitudinal lubrication distribution gallery. The water-inlet manifold has an opening at the centerline of each cylinder through which coolant enters into the lower water jacket of each cylinder. One such opening is shown in section (10) at the number 1 cylinder and in full (11) at the number 2 cylinder. The sectioned opening at the number 1 cylinder connects with lower (12) and upper (13) water jackets. These jackets are connected together across the port belt by a hollow pillar (14). The coolant leaves the block at a point directly above the upper water jacket through holes which register with nozzles (15) in the fire deck of the cylinder head. These nozzles direct the coolant at the exhaust valve seats. From this point the coolant flows upward and around the exhaust-gas passages (16) on the centerline of each cylinder. The engine coolant leaves the cylinder head through a water-outlet manifold connection (17) from which point it then flows to the radiator core (not shown on the exhibit).

Air box passages through which scavenging air is forced by the blower into the cylinders are shown in section at each end of the engine (18) and as a horizontal opening (19) which registers with cylinder liner air-intake ports (20). The inner wall (21) of the number 2 cylinder air-box is sectioned at a point directly above the longitudinal lubrication and engine coolant passageways. In this view of the principle half of the exhibit, the piston in the number 1 cylinder is just at the point of uncovering the scavenging air-intake ports in the cylinder liner (22). At this instant, the 2 poppet valves per cylinder are open to allow the escape of exhaust gases. One of these poppet valves (23) is shown in section at the number 1 cylinder. The absence of poppet-type intake valves on the Series 71 engines permits the use of 2 exhaust valves per cylinder to allow freer breathing. Series 71 engines are now in production with an optional head having 4 exhaust valves per cylinder to provide optimum breathing conditions. Shown at the number 3 cylinder is the laminated-steel compression gasket (24) used to seal compression between the cylinder head and the top of the cylinder liner. Rubber rings (not shown) seal oil and water passages.

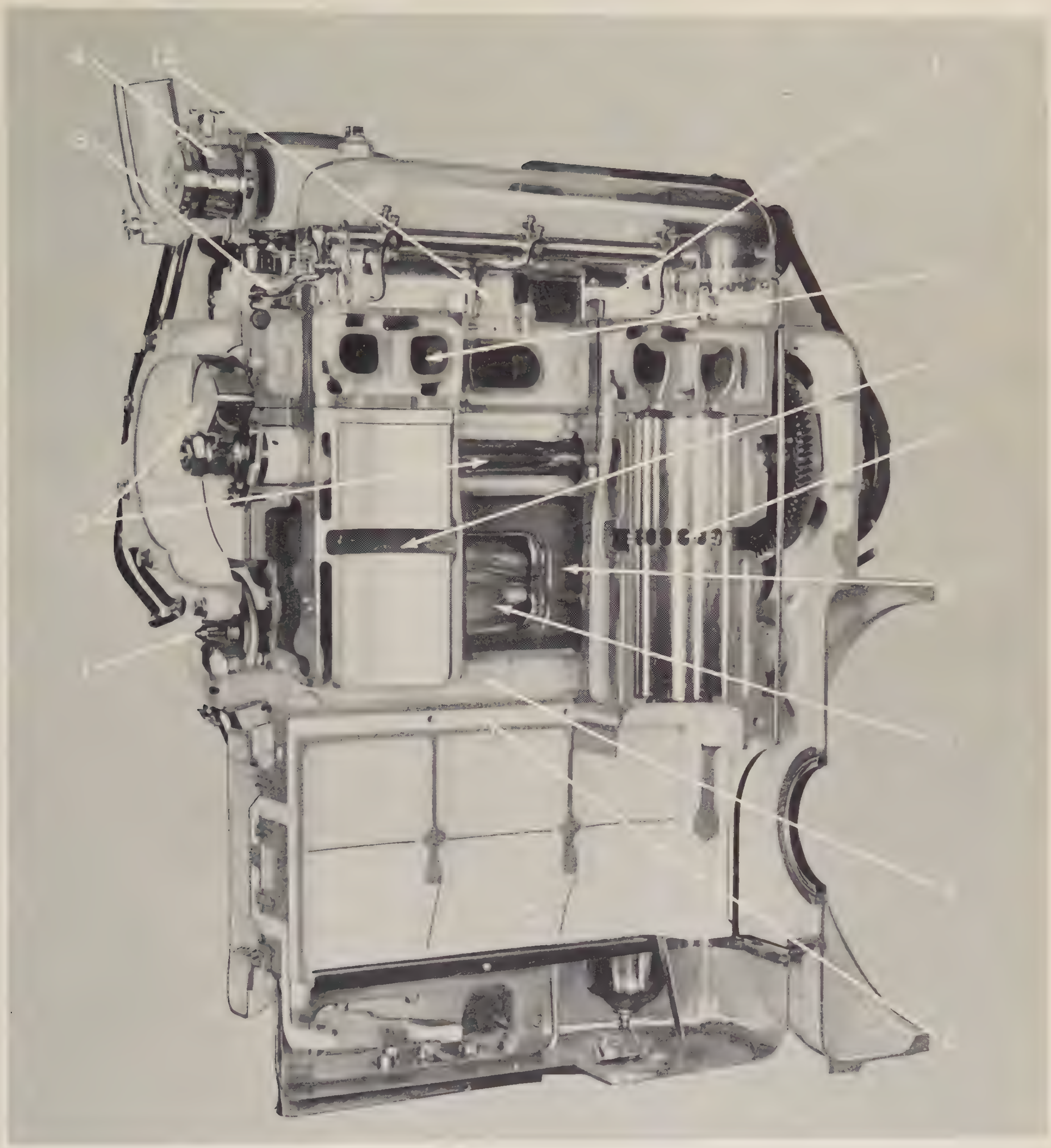


Fig. 3—The *auxiliary* half of the cutaway engine shows such construction details as the water pump (1), the engine-balancer shaft and its rotating counterweight at the front end (2), the engine-speed governor flyweight assembly (not shown in this view) and its associated linkage to individual fuel injectors (3), and the engine-coolant thermostat (4). Also displayed is the oil lubrication gallery (5) and the water-inlet passageway (6) leading to the lower water jackets of each cylinder. This passageway connects with the water pump which is driven by the lower rotor shaft of the scavenging-air blower, the helical lobes of which can be partially seen through the blower-discharge opening (7) in the air-box wall (8) of the number 2 cylinder. The scavenging air-inlet port openings are shown in the number 3 cylinder (9). The horizontal opening, or port belt, through which scavenging air enters the air-intake ports of a cylinder liner is shown at the number 1 cylinder position (10). Also shown in section are the exhaust-gas ports (11) which connect with a separate exhaust-gas manifold and the water-outlet manifold with its connection to the number 2 cylinder (12). The method for transferring the exhaust-gas load from the cylinder head to the wall of the crankcase is displayed by a transverse section (13) between the number 2 and number 3 cylinders. The generator hides a motor and gear set used for animation.

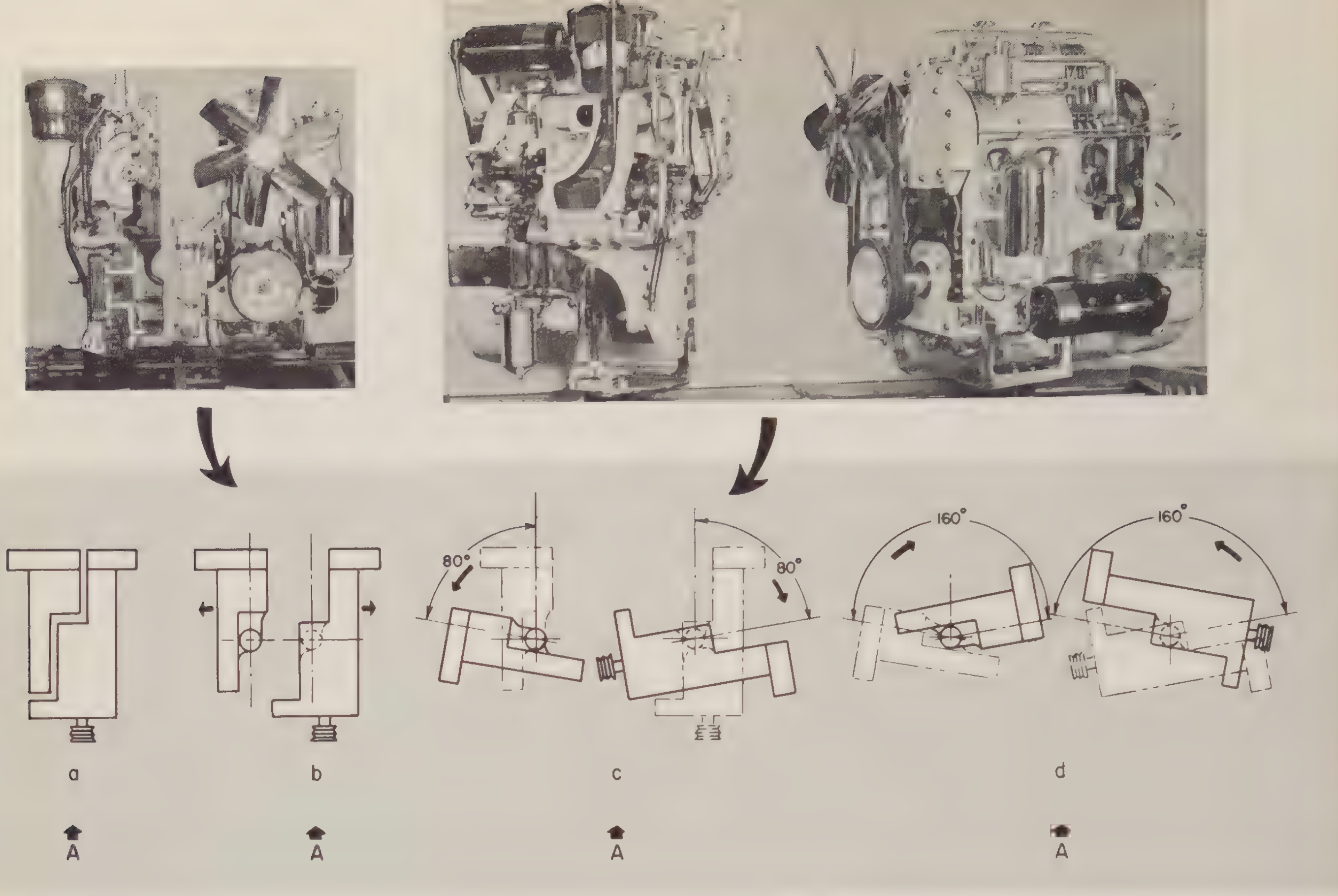


Fig. 4—The cutaway engine is displayed in such a manner that all details on both sectioned halves can be observed from one vantage point. A slider-crank mechanism, 1 for each sectioned half of the engine, provides the oscillatory motion of the display. At the beginning of 1 display cycle, which is accomplished by 1 continuous revolution of the slider crank, both halves of the sectioned engine are in the assembled position (a) so that an observer at *A* views the front end (fan belt end) of the engine. Both halves of the engine then move transversely apart (b). At the end of the transverse movement the 2 halves rotate oppositely 80° (c) on individual support pedestals to assume an "open book" position. At this point an observer at *A* views the outer details of the engine. After a pause of 10 sec both halves of the engine then counter-rotate 160° (d), transferring the "open book" to the observer at *A* who then views the inner construction details of the engine. (The view at this point to the observer at *A* would be similar to that of Figs. 2 and 3.) After another pause of 10 sec, each half counter-rotates 80° and, at the end of rotation, move transversely together to take an assembled engine position (e). The engine halves remain in this position for 15 sec and then move transversely apart. At the end of the transverse movement both halves rotate 80° in a counterclockwise direction (f). An observer at *A* then views the outer details of the engine's auxiliary half and the inner construction details of the principle half, as if the 2 halves had been slid apart along the crank axis. After a 10-sec pause, both halves rotate 160° in a clockwise direction (g). An observer at *A* now views the inner construction details of the auxiliary half and the outer details of the principle half. At the end of a 10-sec pause, both halves rotate 80° in a counterclockwise direction (h). At the end of this rotation, the sectioned halves move transversely together to assume an assembled engine position (a). The cycle is then repeated.

iary half is animated by a 110 volt, 1/12-hp motor having a 68 to 1 gear ratio. The motor and gear set are hidden inside the generator housing. Final reduction and synchronization of speed with the principle half of the engine is made in the generator drive belt and the variable pulley on the generator.

The component parts of the principle half are animated by a 110-v, 1/12-hp motor having a 25 to 1 gear ratio. This motor and gear set, hidden inside the cranking motor housing, use the regular starter and flywheel ring-gear train to turn the engine at approximately 12 rpm. Neither the generator nor cranking motor housing dimensions were changed from those normally used for the Series 71 Diesel engine.

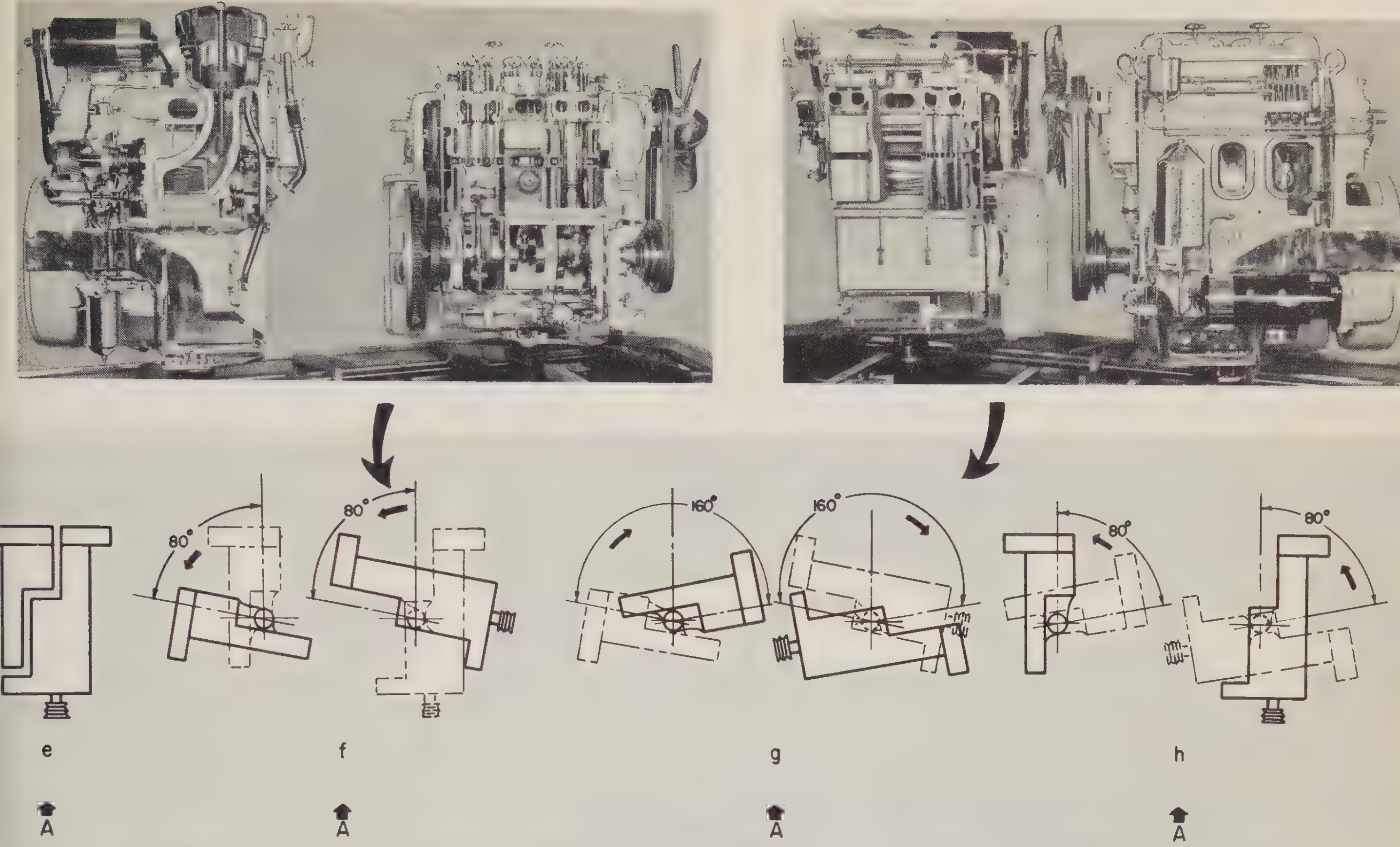
Method of Displaying Cutaway Engine

Much consideration was given to the manner for displaying the cutaway engine. It was realized that the most practical method would be first to separate the 2 halves and then rotate either 1 or both halves. This arrangement, however, presented certain disadvantages. Chiefly, there was the orientation problem presented by the rotating half of the engine with respect to the other half, whether it was stationary or also rotating.

The ideal method of display would be to slide 1 cutaway half of the engine longitudinally with respect to the other half, thereby revealing the sectioned inner components. This arrangement, however, would prohibit offsets in the cutting plane. Also, it would reveal only 1 side of the sectioned engine to an observer who would have to move to the opposite side of the exhibit to view the other sectioned half.

The arrangement finally selected for displaying the exhibit consisted of moving the engine halves apart transversely, oscillating each of them simultaneously, and, finally, returning the halves to the assembled engine position (Fig. 4). This arrangement allows an observer to view all details of the sectioned engine halves from 1 vantage point.

The kinematics of the display is based on the use of 2 similar slider-crank mechanisms (Fig. 5) which provide simultaneous oscillatory motion to both halves of the sectioned engine. One complete display cycle for each cutaway half is accomplished by a single, continuous revolution of the slider-crank mechanism.



The use of oscillation, instead of rotation, to display the engine halves eliminates the need for slip rings and brushes to supply electric power required for moving the cutaway halves through the display cycle. A high-quality wire of the type used for voltmeter leads has proven to be highly successful as a torsionally flexible power line.

Complete stops of the exhibit at the extremes of oscillation occur with continuous drive-motor operation. In displays where an exhibit rotates, complete stops are accomplished with an interruption of motor-power supply. The stop of a rotating exhibit is sudden and its restarting more so as the motor starting windings motivate the exhibit back to its normal speed.

The simple harmonic motion of the oscillating exhibit brings both halves of the sectioned engine to a smooth stop. To produce the desired extended-pause intervals for the exhibit, the motor which drives the exhibit is first stopped and then restarted. The motor comes to full speed before gradually picking up the load of the exhibit.

Exhibit Base

Because the exhibit was planned to be shipped from coast to coast for display at various shows, it was desirable that the weight of the exhibit's base be kept to a minimum to facilitate handling and packaging and minimize transportation costs. However, the base also had to be strong enough to resist damage due to rough handling or accidents while in transit. The requirements were met by using an aircraft type of tubular construction in addition to aluminum castings wherever possible. The assembled exhibit base (Fig. 6) weighs 2,000 lb.

The double slider-crank mechanism is combined with recirculating-ball bushings on the round ways of the exhibit base and recirculating-ball lead screws which advance the exhibit along the ways with a minimum of friction. The friction problem involved in slow moving exhibits of this type results from a large difference in dynamic and static coefficients of friction. When motion starts, the unbalanced force represented by the sudden reduction in the coefficient of static friction produces an acceleration of the exhibit which causes it to move ahead of the lead screw. If the thread lash is sufficient, the exhibit will come to a stop, thereby reverting back to the static coefficient of friction. This results in "chatter." By combining the slider-crank mechanism with recirculating-ball bushings and recirculating-ball lead screws, friction is controlled. Both halves of the sectioned engine exhibit, therefore, may be supported on slender and inconspicuous brackets.

Exhibit Maintenance

The base of the exhibit is designed in such a manner that any required maintenance work on either the base or the component parts of the slider-crank (oscillator) mechanism which it houses can be accomplished without removing the glass enclosure of the display case or the sectioned halves of the engine.

During the design of the drive unit to be used for each of the 2 oscillator mechanisms, a problem arose as to how the units should be designed so that maintenance could be performed easily. Such work would need to be done during the overnight shutdown of the exhibit showing by service technicians who would be unfamiliar with the exhibit details. The design problem was solved by using 1 Detroit Diesel 2-cylinder, Series 71 engine as the basic element for each oscillator mechanism drive unit. This enables the nearest mechanic who is familiar

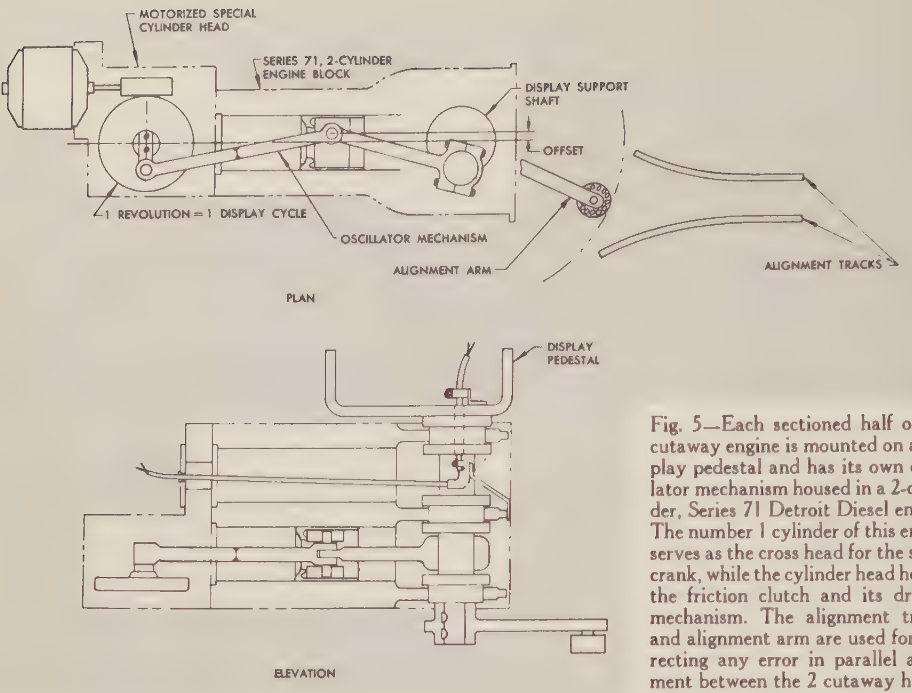


Fig. 5—Each sectioned half of the cutaway engine is mounted on a display pedestal and has its own oscillator mechanism housed in a 2-cylinder, Series 71 Detroit Diesel engine. The number 1 cylinder of this engine serves as the cross head for the slider crank, while the cylinder head houses the friction clutch and its driving mechanism. The alignment tracks and alignment arm are used for correcting any error in parallel alignment between the 2 cutaway halves of the engine.

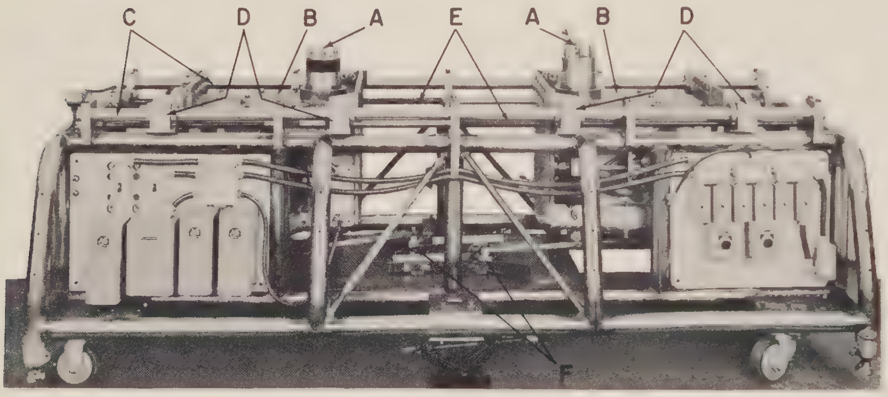


Fig. 6—Requirements for minimum weight with maximum strength for the base of the exhibit were met by an aircraft-type of tubular construction. The display pedestals *A* for each cutaway half of the display engine are mounted in place of the flywheel of the 2-cylinder engines (partially shown at *B*) which house the slider-crank mechanism for each half of the cutaway engine. Other pertinent component parts of the base are way bars (*C*), ball bushings (*D*), lead screws (*E*), and closing alignment tracks (*F*).

with Detroit Diesel engines to comprehend the peculiarities of the installation. Also, the use of the 2-cylinder engines solves the problem of spare parts to a large degree.

Each 2-cylinder engine is installed in the base of the exhibit with its crankshaft in a vertical position. Mounted to the end of each crankshaft, in place of the flywheel, is a pedestal which supports a cutaway half of the engine. The number 1 cylinder of each engine is used as the cross head for each slider-crank mechanism. The number 2 crank throw of each engine provides the means for introducing the electrical power line to either the cranking motor or generator, depending on which half of the cutaway engine is mounted on the 2-cylinder engine. An electrically driven, Series 71 Diesel engine fuel pump is mounted on the 2-cylinder engine to force lubricant through drilled passages in the cylinder block to the crankshaft bearings. These bearings, in turn, may be replaced without removing the crankshaft of the 2-cylinder engine or the cutaway half of the display engine to which it is connected. Attached to the block of each 2-cylinder engine is a specially designed cylinder-head assembly which houses the remainder of the oscillator mechanism. The complete assembly is supported on the ways of the exhibit's base by 4 recirculating-ball bushings which allow the cylinder head to slide off the cylinder block to facilitate repair.

A variation in friction between each 1/12-hp motor reducer used to drive each oscillator mechanism results in a differential speed between each of the cutaway halves of the display engine. Because of this it is necessary to correct mechanically any error in parallel alignment between the 2 cutaway halves developed during 1 display cycle at each closing of the exhibit. This correction is made by entering roller-end levers, on the lower end of the crankshaft, into funnel-mouth alignment tracks. This prevents contact of the 2 halves of the display engine. (Some parts of the exhibit travel a distance of 12 in. with a 1/16-in. parallel clearance between surfaces.) To permit the mechanical alignment, a friction clutch is introduced into the slider-crank drive mechanism because of the irreversible nature of the 1,000 to 1 ratio drive-gear set. To facilitate maintenance, a cranking-motor clutch is used which incorporates an adjusting nut to increase the capacity of the clutch to just meet oscillatory load requirements, thereby avoiding "chatter" of the display during an alignment operation.

Summary

The cutaway exhibit of the 3-cylinder, Series 71 Detroit Diesel engine required careful consideration of 3 factors. The first factor concerned the selection of cutting planes so that all component parts were presented in the clearest possible way for dramatizing inner construction details and operating principles. The second factor concerned the method to use for displaying the exhibit so that maximum visualization of all details would be achieved when the exhibit was viewed from one observation point. Finally, the mechanism used to motivate the exhibit had to be designed in such a manner as to afford maximum ease in maintenance.

The exhibit, completed in 1954, has been displayed in various types of events, such as public boat shows, the 1955 General Motors Motorama, the University of Cincinnati's 50th Anniversary of Cooperative Education, and the GM Powerama. An estimated 5,250,000 people have seen the exhibit at such shows during its first 2 years of operation.

A Summary of Career Opportunities in General Motors

The chart which appears on the next 2 pages is a summary, designed to answer questions often asked of GM interviewers by college students and recent graduates. It has the following objectives:

- **To acquaint the student or graduate with the kinds of work in GM for which he might be employed**
- **To show the locations and addresses of GM Divisions and Central Office Staffs**
- **To help prepare the student or recent graduate for his interview**
- **To act as a ready source of information during the interview or career discussion for students, interviewers, and guidance people**
- **To supply information about General Motors to placement officers, deans, and faculty people who discuss careers with students.**

It should be kept in mind that the chart is a digest rather than a broad summation designed to answer all questions that may be asked by the student or recent graduate. For example, the Divisions of GM have 126 plants in 68 cities in 19 states throughout the U.S., as well as operations overseas and in Canada which also employ college graduates. Only the Divisional and Central Office headquarters in the U.S. appear on the chart. Most of these units have formalized orientation and training programs available in both the technical and non-technical areas. Further information may be found in 2 General Motors publications for those who may be interested. The first is entitled, "The College Graduate and General Motors." Single copies are available to students and may be obtained at the college placement office or by writing General Motors. The second publication, "Job Opportunities in General Motors," describes in some detail GM Staffs, Divisional organizations, and subsidiaries, and outlines career opportunities for graduates of practically every skill and interest. This publication is distributed to colleges only and should be available for use by students in placement offices, libraries, and deans' offices on college campuses.

On the page following the chart are added points of interest for the college student interested in GM. They are concerned chiefly with the question, "How do I go about contacting GM for an interview or facts about employment?"

A Summary of Career Opportunities in General Motors

	Divisions and Staffs of General Motors	Location	Products and Services
CAR DIVISIONS	Buick Motor Division	1051 E. Hamilton Avenue Flint 2, Michigan	Passenger cars
	Cadillac Motor Car Division*	2860 Clark Avenue Detroit 32, Michigan	Passenger cars
	Chevrolet Motor Division*	3044 W. Grand Boulevard Detroit 2, Michigan	Passenger cars and trucks
	Oldsmobile Division	1014 Townsend Street Lansing 21, Michigan	Passenger cars
	Pontiac Motor Division	196 Oakland Avenue Pontiac 11, Michigan	Passenger cars
BODY AND ASSEMBLY DIVISIONS	Buick-Oldsmobile-Pontiac Assembly Division*	3044 W. Grand Boulevard Detroit 2, Michigan	Assembly of passenger cars
	Fisher Body Division*	30001 Van Dyke Avenue Warren, Michigan	Body assembly
	Ternstedt Division*	6307 W. Fort Street Detroit 9, Michigan	Automotive body hardware
ACCESSORY DIVISIONS	AC Spark Plug Division*	1300 N. Dort Highway Flint 2, Michigan	Major automotive and aircraft parts and accessories and electronic equipment for guided missiles and other applications
	Brown-Lipe-Chapin Division*	Town Line Road Syracuse, New York	Automotive accessory parts
	Central Foundry Division*	37 Florence Street Saginaw, Michigan	ArmaSteel and grey iron and malleable iron castings
	Delco Radio Division*	700 E. Firmin Street Kokomo, Indiana	Automobile radios
	Delco-Remy Division*	2401 Columbus Avenue Anderson, Indiana	Automotive electrical equipment and batteries
	Detroit Transmission Division	Willow Run Plant Ypsilanti, Michigan	Passenger car and truck Hydra-Matic automatic transmissions
	Guide Lamp Division	2915 Pendleton Avenue Anderson, Indiana	Automotive electrical lighting equipment
	Harrison Radiator Division*	Washburn at Walnut Lockport, New York	Automotive radiators, thermostats, air conditioning systems, transmission oil coolers, heaters, defrosters, industrial and marine heat exchangers, aircraft oil coolers, and inter-coolers
	Hyatt Bearings Division*	427 Middlesex Street Harrison, New Jersey	Roller and tapered bearings and parts for many industrial applications
	New Departure Division*	269 N. Main Street Bristol, Connecticut	Ball bearings for every application, coaster brakes, steel balls, and sprag clutches
	Rochester Products Division	1000 Lexington Avenue Rochester 3, New York	Carburetors, fuel injection equipment, fuel pumps, tubing, and other equipment
	Saginaw Steering Gear Division	3900 Holland Avenue Saginaw, Michigan	Power and manual steering gears and other products
	United Motors Service Division*	3044 W. Grand Boulevard Detroit 2, Michigan	Automotive service parts and equipment distribution
ENGINE DIVISIONS	Allison Division*	4700 W. 10th Street Indianapolis 6, Indiana	Turbo-jet and turbo-prop aircraft engines, heavy-duty transmissions for ordnance and commercial vehicles, Diesel locomotive parts, precision bearings, and Aeroproducts propellers
	Cleveland Diesel Engine Division	2160 W. 106th Street Cleveland 11, Ohio	Large marine Diesel and stationary gas engines and free piston gasifiers
	Detroit Diesel Engine Division	13400 W. Outer Drive Detroit 28, Michigan	Diesel engines for marine, industrial, petroleum, transportation, and construction equipment

Kinds of Work for which Graduates Are Employed

- Accounting
- Legal
- Patent
- Personnel
- Plant Engineering (planning, developing, and installing and maintaining plant facilities and services)
- Product Engineering (design, development, and testing)
- Production Engineering (processing, methods, time study, machine layout, plant layout, and machine, die, and tool design)
- Purchasing
- Research and Development
- Sales and Service†
- Styling and Design (industrial design, mechanical design, and creative engineering)
- Training for Supervision in Manufacturing† (fabrication, assembly, inspection, production control, packaging, materials handling, and receiving and shipping)

Kinds of Graduates Employed

- Business (business administration, marketing, accounting, and finance)
- Engineering (mechanical, electrical, industrial, metallurgical, chemical, aeronautical, civil, and ceramic)
- Law
- Liberal Arts (all majors)
- Science (physicists, chemists, and mathematicians)
- Others (foundry, styling, and design)

These Divisions have plant locations in other cities in addition to the addresses shown. These locations may be found in the booklet, "The College Graduate and General Motors." These plants also have facilities for interviewing college graduates.

†Opportunities for both technical and non-technical graduates.

A Summary of Career Opportunities in General Motors

	Divisions and Staffs of General Motors	Location	Products and Services	Kinds of Work for which Graduates Are Employed	Kinds of Graduates Employed
ENGINE DIVISIONS (Cont.)	Diesel Equipment Division	2100 Burlingame, S.W. Grand Rapids 1, Michigan	Diesel fuel injectors, hydraulic valve lifters, gas turbine fuel nozzles, and other components	• Accounting • Legal • Patent • Personnel • Plant Engineering (planning, developing, and installing and maintaining plant facilities and services) • Product Engineering (design, development, and testing) • Production Engineering (processing, methods, time study, machine layout, plant layout, and machine, die, and tool design) • Purchasing • Research and Development • Sales and Service† • Styling and Design (industrial design, mechanical design, and creative engineering) • Training for Supervision in Manufacturing† (fabrication, assembly, inspection, production control, packaging, materials handling, and receiving and shipping)	• Business (business administration, marketing, accounting, and finance) • Engineering (mechanical, electrical, industrial, metallurgical, chemical, aeronautical, civil, and ceramic) • Law • Liberal Arts (all majors) • Science (physicists, chemists, and mathematicians) • Others (foundry, styling and design)
	Electro-Motive Division*	9301 55th Street La Grange, Illinois	Diesel locomotives, mobile generating plants and large Diesel engines		
	Euclid Division	1361 Chardon Road Cleveland 17, Ohio	Earthmoving equipment		
	Fabricast Division*	Third and Monon Streets Box 271 Bedford, Indiana	Light alloy castings and heat-resistant heavy alloy castings for the automotive, locomotive, aircraft, and other industries		
DAYTON, HOUSEHOLD APPLIANCE AND GMC TRUCK DIVISIONS	Delco Appliance Division	391 Lyell Avenue Rochester 1, New York	Automotive appliance motors, servomechanisms, home heating and air conditioning, fractional hp motors, and electrical and electronic controls		
	Delco Products Division	329 E. First Street Dayton 1, Ohio	Fractional hp and industrial motors, a-c and d-c generators, electrical and hydraulic control devices, and automotive suspension units		
	Frigidaire Division	300 Taylor Street Dayton 1, Ohio	Electric appliances for home and industrial use		
	GMC Truck and Coach Division	660 South Boulevard E. Pontiac 11, Michigan	Trucks, commercial vehicles, coaches, and buses		
	Inland Manufacturing Division	2727 Inland Avenue Dayton 1, Ohio	Rubber, plastic, metal, and friction material products		
	Moraine Products Division	1420 Wisconsin Boulevard Dayton 1, Ohio	Hydraulic brake equipment, bearings, and powder metal products		
	Packard Electric Division	Dana Street, N.E. Warren, Ohio	Automotive and aircraft cable products and fractional hp motors		
GM CENTRAL OFFICE TECHNICAL STAFFS	Engineering Staff (including GM Proving Ground)	GM Technical Center Detroit 2, Michigan	Advanced engineering design, development and testing of automotive products		
	Process Development Staff	GM Technical Center Detroit 2, Michigan	Manufacturing research and development of new production techniques		
	Research Staff	GM Technical Center Detroit 2, Michigan	Fundamental and long-range scientific and engineering research for the advancement of technology		
	Styling Staff	GM Technical Center Detroit 2, Michigan	Appearance design for both automotive and non-automotive products		
CANADIAN GROUP	Frigidaire Products of Canada, Limited*	Scarborough, Ontario Canada	Frigidaire and Delco heat products for Canada		
	General Motors of Canada, Limited*	William Street E. Oshawa, Ontario Canada	Manufacture and assembly of GM cars, trucks, and automobile engines in Canada		
	General Motors Diesel, Limited	East Oxford Street London, Ontario Canada	Diesel locomotives, engines, and power generating units		
	McKinnon Industries, Limited	Ontario Street St. Catharines, Ontario Canada	Parts, assemblies, V-8 engines, and accessories for Canadian-built passenger cars and trucks and other automotive parts and products		
FINANCE AND INSURANCE GROUP	General Motors Acceptance Corporation	1775 Broadway New York 19, New York	Wholesale and retail financing for dealers in GM Products	• Accounting • Finance • Law • Personnel • Public Relations • Purchasing • Insurance • Sales and Service† *Offices of these units are located throughout the U. S. Contacts for employment information may be made to these zone and branch offices or to the addresses indicated. Consult the telephone directory for addresses of local offices*	• Business Administration • Finance • Liberal Arts (all majors) • Marketing • Mathematics
	General Exchange Insurance Corporation	1775 Broadway New York 19, New York	Fire, theft, and collision insurance for automobiles		
	Motors Insurance Corporation	1775 Broadway New York 19, New York	Fire, theft, and collision insurance for automobiles		
	Motors Holding Division of General Motors	3044 W. Grand Boulevard Detroit 2, Michigan	Capital and financing for retail dealers in GM automobiles		
	Yellow Manufacturing Acceptance Corporation	3044 W. Grand Boulevard Detroit 2, Michigan	Wholesale and retail financing for GMC trucks, Euclid earthmoving equipment, Detroit Diesel engines, and allied heavy-duty equipment		

**These Divisions have plant locations in other cities in addition to the addresses shown. These locations may be found in the booklet, "The College Graduate and General Motors." These plants also have facilities for interviewing college graduates.*

†Opportunities for both technical and non-technical graduates.

Information About Other GM Units

There are a number of other units within General Motors which are not listed on the preceding chart because they either differ considerably in their responsibilities and functions from those listed or warrant special comment in regard to the employment possibilities and information they have to offer the college graduate. The chart below clarifies the employment picture in regard to these. All of these units, with the exception of General Motors Institute, do not generally employ college people immediately upon graduation. Rather, they normally hire college graduates, who have gained considerable experience related to the more specialized functions of these Staffs, either by way of promotion from within GM or from outside.

	Divisions and Staffs of General Motors	Location	Responsibilities and Functions	Kinds of Work for which Graduates Are Employed	Kinds of Graduates Employed
GENERAL MOTORS CENTRAL OFFICE STAFFS	General Motors Institute	Chevrolet at Third Flint 2, Michigan	Full-time cooperative engineering, business administration, and dealer training programs	• Teaching	• Business • Engineering • Liberal Arts • Science • Others
	Financial Staff	3044 W. Grand Boulevard Detroit 2, Michigan and 1775 Broadway New York 19, New York	Financial analysis in the determination of operating policies of management	• Accounting • Finance • Insurance	• Accounting • Business Administration • Finance • Mathematics
	Business Research Staff	3044 W. Grand Boulevard Detroit 2, Michigan	Long-range studies of economics and business trends for the guidance of management	These Staffs offer opportunities primarily for graduates in Liberal Arts and Business Administration	
	Distribution Staff	3044 W. Grand Boulevard Detroit 2, Michigan	Co-ordination of overall product sales and service activities, policies, and problems		
	Manufacturing Staff	3044 W. Grand Boulevard Detroit 2, Michigan	Co-ordination of scheduling procurement, real estate, transportation, communications, and other manufacturing activities		
	Personnel Staff	3044 W. Grand Boulevard Detroit 2, Michigan	Co-ordination of labor relations and personnel administration activities		
	Public Relations Staff	3044 W. Grand Boulevard Detroit 2, Michigan	Interpretation of GM policies to the public and keeping management informed of public attitudes		
	Legal Staff	3044 W. Grand Boulevard Detroit 2, Michigan and 1775 Broadway New York 19, New York	General control of all matters of legal import concerning GM	*College students interviewed directly upon graduation and after having passed the Bar examination. Lawyers with experience, and by virtue of their specialization, also employed from outside GM*	
	Argonaut Realty Division	485 W. Milwaukee Detroit 2, Michigan	Real estate, rental and leases, building design, and supervision of building construction	*Opportunities for Architectural Engineers, as well as Business, Engineering, Liberal Arts, Science, and Other categories*	
OVER-SEAS	General Motors Overseas Operations Division	1775 Broadway New York 19, New York	Manufacturing and distribution of GM products outside the U.S. and Canada	**Opportunities for Engineering, Liberal Arts, and Business Administration graduates in Detroit and New York offices, but not usually for overseas assignment**	

Securing a GM Interview and Employment Information

Information

College graduates and near graduates interested in a future with General Motors can contact their placement officers for information about GM and its Divisions. If you are interested in more specific information about the Division of your choice, information is available in the publications described on the introductory page to the chart, or at the Divisional and Staff central offices indicated on the chart.

Interviews

Members of the General Motors Personnel Staff are acquainted with current Divisional and Staff employment requirements and opportunities. They visit campuses to interview students interested in an industrial career, in order to select those who qualify for employment consideration somewhere in the GM organization.

After the campus interview, qualification summaries of selected students are referred to the GM units having employment openings. Upon review of these summaries, a Division or Staff activity may then invite the student for an interview regarding a specific job assignment or training program. This on-the-spot interview gives members of management an opportunity to meet the graduate and, in turn, gives the graduate an opportunity to see the organization and the job before any commitments are made. Final employment of graduates rests entirely with the individual Divisions and Staffs.

If General Motors representatives are not scheduled to visit your campus and you are interested in GM employment opportunities, contact any of the units listed on this chart, or 1 of the 3 following offices:

Director
Salaried Personnel Placement
General Motors Corporation
9-260 General Motors Building
Detroit 2, Michigan

Manager
Dayton Salaried Personnel Placement
General Motors Corporation
816-817 Winters Bank Building
Dayton, Ohio

Manager
New York Salaried Personnel Placement
General Motors Corporation
1826 General Motors Building
New York 19, New York

This chart can be obtained either singly or in quantities by writing the above Detroit address.

Applying Physics in Industry: How Studies of Vibration and Noise Aid Developmental Work

By DAVID C. APPS
General Motors
Proving Ground

In a physics classroom, the student studies a number of topics such as mechanics, heat, light, electricity, and magnetism. Another is *sound* and this subject has very definite, interesting, and useful applications in industry. This is particularly true in automotive design work. Here, an understanding and application of the principles of sound is especially stimulating and challenging because the 3 areas of vibration, noise, and stress often are represented in separate problems, yet they are so closely related that the solution in one area sometimes is obtained by a solution in another. The engineer learns to think of one area in terms of the other. He also learns to think of a mechanical or acoustical problem in terms of an electrical circuit, and there is a firm mathematical basis for this. Design problems related to engines, transmissions, drive lines, automotive frames, and fans are typical ones where vibration, noise, and stress must be handled. Such problems also are unified by the instrumentation, techniques, and equipment used, which often result in a common approach. Engineering development in General Motors is aided by attention to the fields of sound, vibration, and stress at the Noise and Vibration Laboratory of the GM Proving Ground, located at Milford, Michigan.

Problems in noise, vibration, and stress often are intimately interrelated

The problems encountered in a modern noise and vibration laboratory afford an excellent opportunity for the engineer to develop and exercise a considerable variety of engineering skills. This situation follows from the fact that noise, vibration, and dynamic stresses are concomitant physical processes. To work successfully in one field frequently requires the skill, equipment, and instrumentation used in the other 2 fields.

Perhaps in no other industrial activity is this truth more obvious than in the automotive field where the 3 specialties are interwoven in an inseparable pattern.

Perhaps the theme sounded above can best be demonstrated by referring to a diagram representing the relationship of vibration, noise, and stress (Fig. 1). The central location of a square labeled "vibration" indicates that it is the common, or central, phenomenon to which audible noise and mechanical stress are related. For example, a vibration problem may cause vibration discomfort alone; this is to say that in this case there is neither a noise nor a stress problem. This situation usually occurs in a low-frequency vibration.

On the other hand, a vibration may produce a severe noise problem, a matter of human discomfort. Stated in an inverse fashion, it could be said that to work successfully on this noise problem, the engineer must investigate the underlying vibration problem.

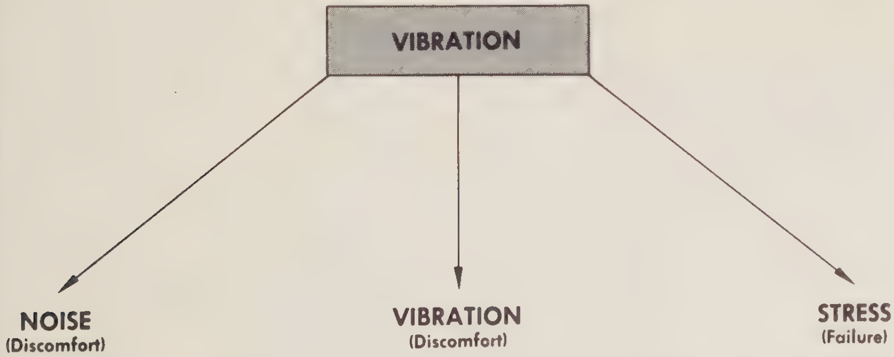


Fig. 1—The relationship of vibration, noise, and stress is represented by this diagram. It may be called a phenomenological relationship. The location of the rectangle labeled *vibration* denotes that it is the common, or central, phenomenon to which audible noise and mechanical stress are related. A vibration may produce a vibration discomfort alone, or it may produce a noise discomfort or a stress problem indicated by a fatigue failure.

Alternately, a vibration may lead to a stress problem, the outward indication of which is a fatigue failure. In order to cope successfully with this fatigue problem, the engineer may very well have to direct his attention to the underlying vibration problem.

As will become apparent later, not all noise problems require that the engineer choose to deal with the underlying vibration problem nor in all stress problems does the engineer find an underlying vibration problem.

Loud Speaker or Motor Illustrates Vibration, Sound, and Stress

Some of the principles of vibration, noise, and stress can be demonstrated starting with the relationship between mechanical vibration and sound. The vibration of a loud speaker cone, for example, produces a (desired) sound. An electric motor produces noise because the magnetic forces cause vibration of the housing. A gasoline engine radiates sound directly from the cylinder block because gas explosions impulsively distort the structure in a most complex pattern, radiating sound in so doing. The bridge between vibration and sound, cause and effect, can easily be seen from the above examples. To work effectively on these sound problems requires an understanding of the underlying vibration problem. It is of interest to recognize that there are precise mathematical relationships between the vibration of a surface and the sound pressure generated. These relationships for idealized situations are found in standard texts[1]. For instance, the pressure amplitude p_o at a point q due to the vibration of a piston

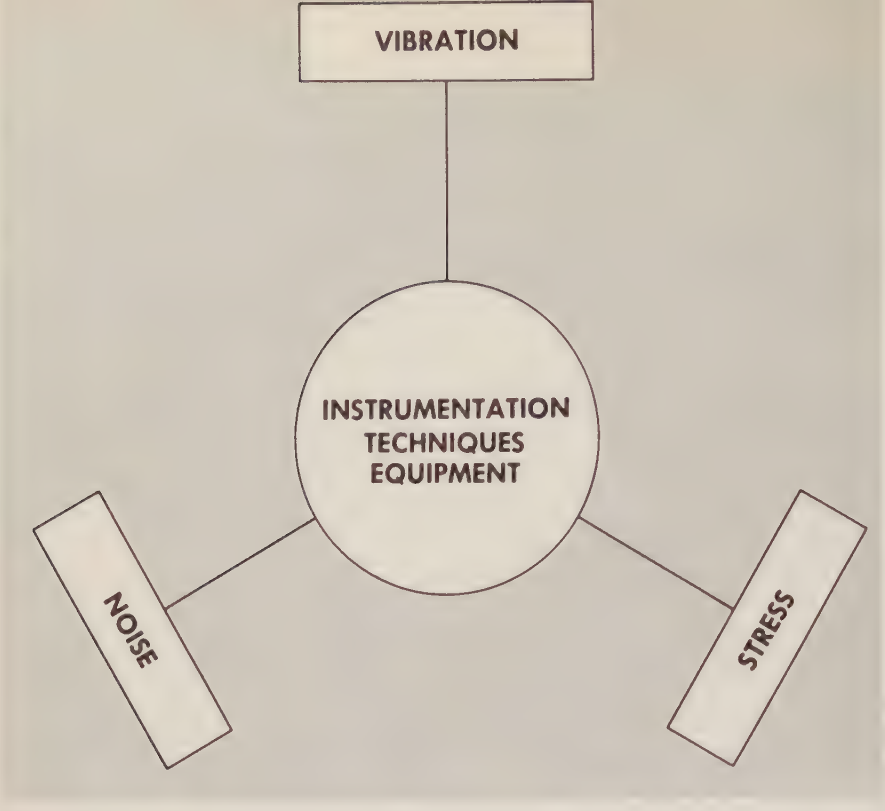


Fig. 2—Instrumentation, techniques, and equipment further unify problems in vibration, noise, and stress. Some of the same measuring techniques are used in studying all of the 3 types of variables.

located in an infinite baffle is a function of:

f = frequency of vibration (cycles per second)
a = radius of the piston (cm)
X_o = displacement amplitude of the piston (cm)
r = distance to point q (cm)
θ = angle between point q and the axis of the piston (degrees)
ka = ratio of the circumference of the piston to the wavelength of sound.

The pressure amplitude p_o at a point q can be expressed by the following equation:

$$p_{oq} \approx \frac{f^2a^2X_o}{r}\left[\frac{2J_1(ka\sin\theta)}{ka\sin\theta}\right] \qquad (1)$$

where

J_1 = a Bessel function of the first order for cylindrical coordinates; a sinusoidal piston motion is assumed.

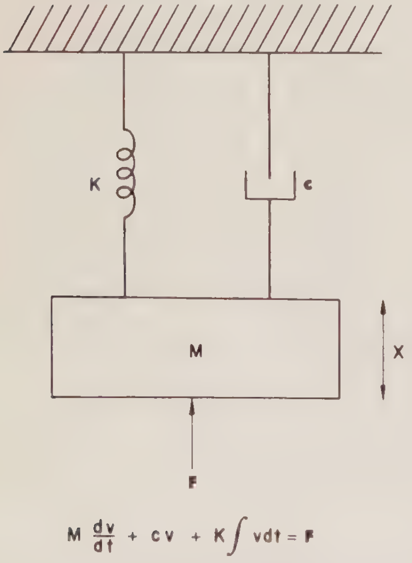


Fig. 3—An electro-mechanical analogy is useful to the engineer in visualizing vibration and sound problems. This diagram represents a simple, parallel mechanical system having lumped constants of mass M, viscous damping c, and spring rate K moving in the direction x due to force F. By summing the instantaneous forces, the equation of motion shown can be derived.

Again referring to the principles of vibration, noise, and stress, the tie between vibration and stress, as with vibration and sound, is no less obvious. It is difficult to imagine any vibrating system without concomitant stress. The suspension of the loud speaker, mentioned above, is stressed during vibration as is each annular zone of the cone, since each must accelerate that aggregate mass lying outward toward the edge of the cone. The housing of the electric motor is obviously stressed as it is deformed by the magnetic forces, and, of course, the same is true for the engine block. Thus, the noise-vibration-stress relationship can be most generally stated as follows: vibration, in general, may produce (a) noise, a problem in passenger comfort, (b) a problem in passenger comfort because of the vibration per se, or (c) stress, a problem in mechanical failure.

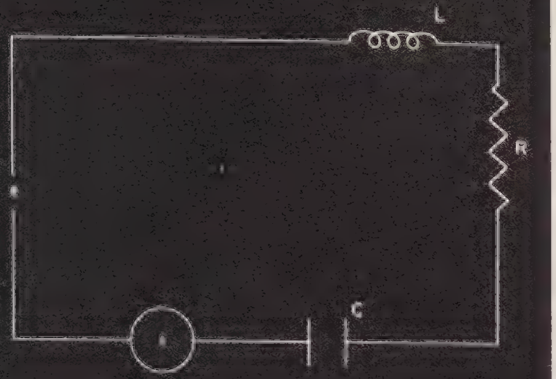
Another way in which the 3-cornered area of noise, vibration, and stress is tied together is illustrated by considering that the unifying elements include instrumentation, equipment, and techniques (Fig. 2). A moment's reflection will show that these unifying attributes occur quite apart from a simple relationship (Fig. 1), which might be called "a phenomenological relationship."

The physical variables of sound, vibration, and stress are of such a nature and/or magnitude that transducers, or sensing devices, are used to detect them. These sensing devices yield minute electrical voltages. The common factor, then, in handling these small voltages so sensed are the amplifiers and other electronic instruments used to record or analyze them. For example, the complex electrical signals of a given noise must frequently be analyzed into their several frequency components. In practice this is done by the use of a wave analyzer and an automatic level-recording device, which automatically plots the frequency components with respect to their respective amplitudes. This plot is called a spectrum. However, it is frequently necessary to perform exactly the same operation on a complex vibration signal or a complex stress signal; thus, the automatic wave analyzer and recorder are used to perform the same operation on signals obtained from any of the 3 classes of variables (Fig. 2).

Other examples of common instrumentation requirements are numerous; for example, it is a usual practice to make multi-channel recordings of vibration and of stress. Thus, multi-channel amplifiers are needed, 1 channel for each strain gauge or vibration pickup, to amplify the small sensed signal to a level sufficiently high to be recorded on a multi-channel magnetic oscillograph. Again, the same basic instrument sequence is used for both, often simultaneously.

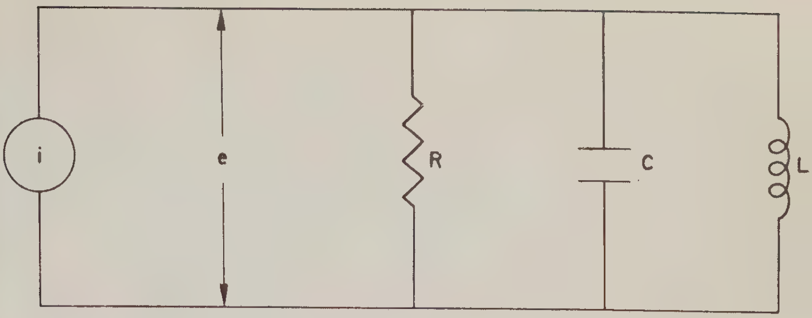
In the way of equipment, chassis and engine dynamometers are indispensable for successfully coping with automotive noise problems. The same chassis dynamometer, however, can double for use in the study of vibration and stress problems.

Another unifying factor is found in the electro-mechanical (and electro-acoustical) analogies which enable the engineer to think of a mechanical problem in



$$L\frac{di}{dt} + Ri + \frac{1}{C}\int idt = e$$

Fig. 4—The equation of Fig. 3 is analogous to the above equation for a series electrical circuit having lumped constants of inductance *L*, resistance *R*, and capacitance *C* and excited by the voltage *e*. Being a 1-loop circuit and thus "constrained" to current flow in a single pattern, the instantaneous voltages can be summed and equated to *e* in a single equation, similar to the mechanical example of Fig. 3.



$$C\frac{de}{dt} + \frac{1}{R}e + \frac{1}{L}\int edt = i$$

Fig. 5—A parallel electrical circuit can be used to represent a parallel mechanical system. Above is a circuit having lumped constants of inductance *L*, resistance *R*, and capacitance *C* and excited by current *i*. Here the differential equation is obtained by summing the instantaneous currents to each of the branches.

terms of an electrical circuit. In fact, the analogy theory is not merely a useful concept for thinking but rather a precise relationship established on a firm mathematical basis. This relationship permits detailed analysis of mechanical or acoustical systems in terms of electrical circuit theory.

For example, consider a simple, parallel mechanical system which consists of "pure" lumped constants and is constrained to move in the *x* direction (Fig. 3). By summing the instantaneous forces, the following differential equation of motion can be derived:

$$M\frac{dv}{dt} + cv + K\int vdt = F \qquad (2)$$

where

M = mass (lb-sec² per in.)
c = viscous damping (lb per in. per sec)
K = spring rate (lb per in.)
F = force moving the system (lb)
v = velocity (in. per sec)
t = time (sec).

The engineer recognizes equation (2) as analogous to the familiar equation for a *series* electrical circuit of 1 loop (that is, no coupling and thus constrained to current flow in a single pattern), in which the instantaneous voltages are summed and equated to the applied voltage *e* (Fig. 4). This results in the following quation:

$$L\frac{di}{dt} + Ri + \frac{1}{C}\int idt = e \qquad (3)$$

where

L = inductance (henry)
R = resistance (ohm)
C = capacitance (farad)
e = voltage (*v*)
i = current (amp)
t = time (sec).

If it is chosen to represent the parallel mechanical system with a parallel electrical circuit, a differential equation follows from summing the instantaneous currents to each of the branches (Fig. 5). For this circuit, the equation is:

$$C\frac{de}{dt} + \frac{1}{R}e + \frac{1}{L}\int edt = i \qquad (4)$$

where the symbols are as defined in equation (3).

By comparing terms in equations (2), (3), and (4), it is concluded that the following quantities are analogous:

Column 1	Column 2	Column 3
Parallel Mechanical	*Series Electrical*	*Parallel Electrical*
M	L	C
K	$1/C$	$1/L$
c	R	$1/R$
F	e	i
v	i	e

It is interesting to note that the same analogous quantities result if a series mechanical system is initially drawn. That is, parallel-parallel (equations 2 and 4) or series-series representation yield the so-called mass-capacitance analogy (Columns 1 and 3) and series-parallel or parallel-series (equations 2 and 3) representation yield the mass-inductance analogy (Columns 1 and 2). Reference to standard texts is suggested for further details[2, 3, 4].

The well-known expression for the steady-state current I_o in the series electrical circuit (Fig. 4), excited by a sinusoidal voltage of amplitude E_o, is expressed by solving for the particular integral of equation (3) with $E_o \sin\omega t$ replacing *e* on the right side of the equation. Therefore,

$$I_o = \frac{E_o}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega c}\right)^2}} \qquad (5)$$

where

$$\omega = 2\pi \text{ (frequency)}.$$

It follows from comparing analogous quantities in Columns 1 and 2 above that the steady-state velocity amplitude V_o in the parallel mechanical system (Fig. 3), excited by a sinusoidal force of amplitude F_o, can be expressed by the following equation:

$$V_o = \frac{F_o}{\sqrt{c^2 + \left(\omega M - \frac{K}{\omega}\right)^2}}. \qquad (6)$$

The displacement amplitude X_o rather than the velocity amplitude V_o is frequently of more interest. The displacement amplitude can be obtained by dividing the velocity amplitude (equation 6) by $j\omega$, where $j \simeq \sqrt{-1}$. This will give the following equation for the displacement amplitude X_o:

$$X_o = \frac{F_o}{\sqrt{(\omega c)^2 + (\omega^2 M - K)^2}}. \qquad (7)$$

Solving Typical Problems Requires Understanding of Measurement Techniques

With this brief background of the relationship of noise, vibration, and stress analysis, a further understanding of their applications can be gained from a descrip-

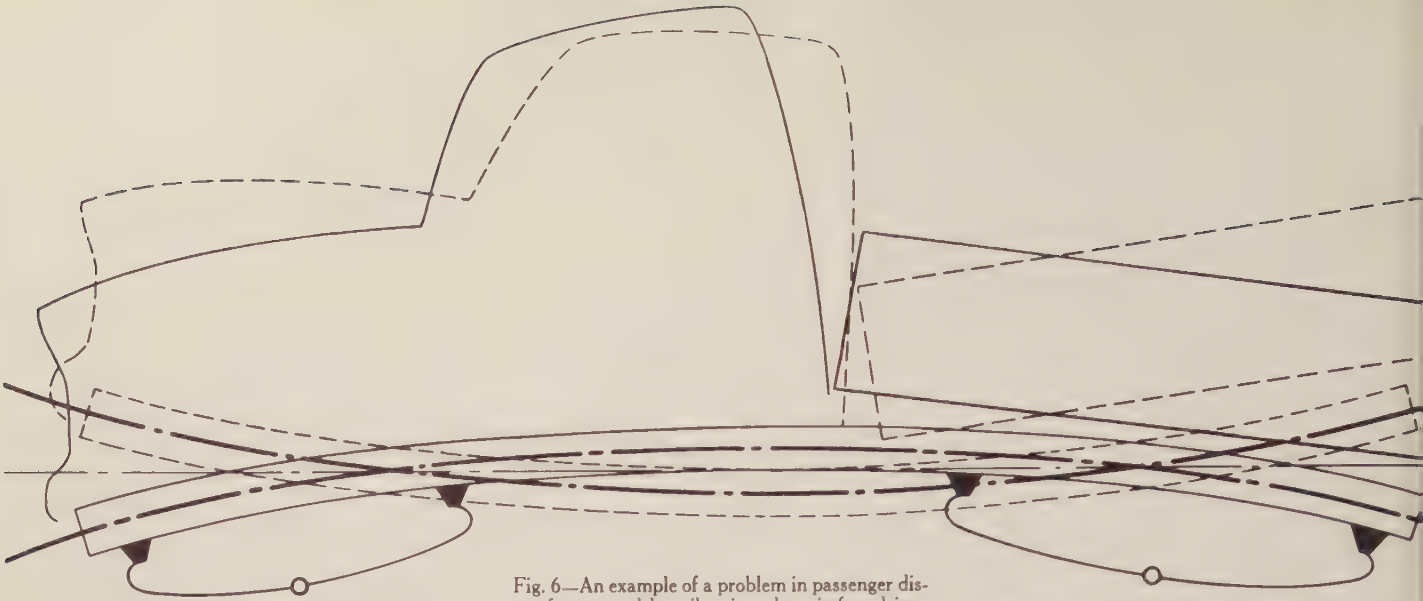


Fig. 6—An example of a problem in passenger discomfort caused by vibration alone is found in a truck chassis design. This diagram represents the pattern or mode of vibration of the chassis as a free-free beam, excited by rough roads. Instrumentation showed the maximum displacement amplitude at the center of the frame. The cure was to stiffen the frame in vertical flexure by increasing the sectional moment of inertia.

tion of some of the typical problems encountered by engineers working in these fields.

The measurement of sound appears deceptively simple. The alternating sound pressure, for example, is sensed by a microphone. The resulting electrical signal is amplified in a conventional amplifier, the output of which drives a rectifier type of indicating meter. Sound pressure measurements may be expressed in linear units, such as psi or dynes per cm². It is common practice, however, to express the rms pressure P in terms of a sound pressure level SPL, where the level is expressed in decibels above a standard rms reference level of 0.0002 dynes per cm². An equation for SPL, expressed in decibels, is as follows:

$$SPL = 20 \log_{10} \frac{P}{0.0002}. \qquad (8)$$

A typical sound pressure in a modern car might be 80 db, equivalent to 2 dynes per cm².

The neophyte soon learns, however, that the measurement of sound is not as simple as measuring voltage in an electrical circuit. The reason? Wavelengths of audible sound are neither small nor large compared with the dimensions of sound sources, interfering objects in the sound field, or enclosures. As a result, one becomes painfully aware of the fact that in the general case sound is a field problem in which sound pressure varies with the x, y, and z coordinates, as well as with time. Thus, when measuring sound level in an enclosure such as a car body, account must be taken of standing waves in which a significant variation of SPL may be found by moving the microphone a few inches.

In situations where the dimensions of the system are small compared with the wavelength of sound, the field system degenerates to a 1-dimensional problem where time is the only independent variable. Here the system can be treated as one of lumped constants, exactly as in an electrical circuit in which dimensions are small compared with the electrical wavelength.

Practical problems in sound control in the automobile, truck, and bus are largely 3-dimensional. Because analytical treatment of such problems are prohibitively complex, as suggested in the discussion of vibration and sound relationships, the experimental approach is used almost entirely, guided by basic acoustical principles. For example, the additional sound level reduction, Δ db, obtained by the use of additional sound absorption materials in a reverberant sound field, is governed by the following relation:

$$\Delta \text{ db} = 10 \log_{10} \frac{A_1 + A_2}{A_1} \qquad (9)$$

where

A_1 = initial absorption (sabins)
A_2 = added absorption (sabins).

This relation becomes a guide to the design of an experiment. To determine whether the addition of A_2 sabins is effective in practice from a passenger's viewpoint, binaural tape recordings are made for each condition and the recordings played back to a jury. This is an extremely sensitive method of detecting small changes in a realistic manner[5].

In a similar manner, the transmission loss TL of sound through a panel, such as a car floor, is proportional to a first approximation, to the product of the surface density (mass per unit area) of the panel, and the frequency of the sound. This is the so-called mass-law. The noise reduction NR, expressed in decibels, obtained by interposing a complete enclosure of such a panel between a noise source (such as the automobile engine) and the area to be isolated (such as the body interior where the passengers are) follows the relation:

$$NR = TL - 10 \log_{10} \frac{S}{A} \qquad (10)$$

where

S = area exposed to the noise
A = total sound absorption of interior trim (sabins).

This relation will help to govern the choice of materials for improved sound control. However, in practice other factors tend to limit the noise reduction which might be expected from increasing the surface density and hence the TL of the floor panel or panels. Again the solution is to test the effect of the panel in place, under conditions where these factors are operative. Some of these other factors include the transmission of sound energy through parallel paths, such as the window area and fire wall. Thus, regardless of how perfect a sound barrier may be used for the floor, the sound level reduction is limited according to the relative transmission of the various areas. This situation is analogous to parallel electrical paths where increasing the

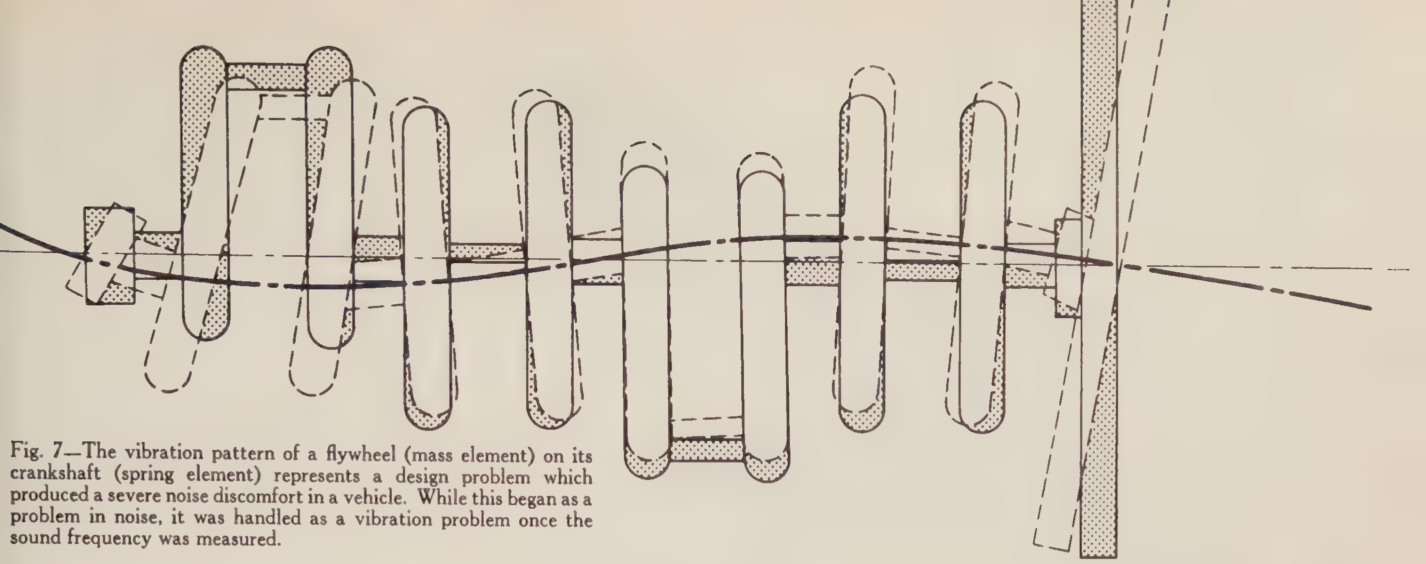


Fig. 7—The vibration pattern of a flywheel (mass element) on its crankshaft (spring element) represents a design problem which produced a severe noise discomfort in a vehicle. While this began as a problem in noise, it was handled as a vibration problem once the sound frequency was measured.

resistance or impedance of the higher resistance path produces no significant effect when this path is of the order of 10 or more times the other.

The range of problems in the field of automotive noise control alone is indeed a wide one, and the engineer may find himself working on any or all of them. The reciprocity theorems of Rayleight and Helmholtz have new meaning when used for the absolute calibration of microphones. The design of mufflers helps to remove the barriers tending to compartmentize the theory of acoustical, mechanical, and electrical filters. Tire disturbances, transmitted through the structure as mechanical vibrations, emerge as an audible noise problem.

From the field of sound, the engineer then steps across the line into the field of mechanical vibration, a line which becomes diffused if not obliterated as he gains experience. Here, again, both *field* problems and *circuit* problems exist. The vibration of a beam, for example, is derived from partial differential equations in 1 coordinate, in addition to time—a significant simplification with respect to the 3-dimensional sound field. The simpler, lumped-constant systems are found at low frequencies, so that, as with sound, the wavelength is long compared with the dimensions of the system. However, in addition to length, the loading and stiffness are equally significant factors[4]. The low-frequency problems in vibration tend to place them in the discomfort class, as for example, problems in ride motions—about 1 per second—and so-called secondary vibrations, or wheel hop—about 10 per second.

Vibrations in the audible range tend to become sound problems as well, and perhaps fatigue problems. Vibrations tend toward the problem class in those cases where the motion consists of 1 or 2 harmonic terms, in contrast to sound problems which frequently have a *white* or uniform spectrum. In general, however, both noise and vibration problems have the same exciting sources, such as engine rotational frequency, firing frequency, or gear tooth frequencies.

Vibration systems of the lumped-constant class can be instrumented much like lumped-constant acoustical or electrical systems, that is with a single vibration pickup. Many vibration problems are coupled systems in which a pickup must be used for motion measurement of each of the coupled elements. This is analgous to using an ammeter in each of the loops of a multi-loop electrical circuit.

In vibration problems of the *field* type —occurring at higher frequencies, perhaps 10 cps and above for the complete car structure—the motion at proportionately more stations must be surveyed either simultaneously with a multiple array of pickups or successively with perhaps 1 pickup. Frequently 10 or more pickups are displaced on the car. The motions recorded on a multiple-channel magnetic oscillograph yield information on relative phase, amplitude, and frequency of the various points of the structure, enabling the construction of a physical picture of the mode, or pattern, of vibration. This, in turn, leads to the design of corrective changes.

As stated earlier, vibration problems frequently lead to fatigue and failure of a component or structure. The interest here is primarily with repeated stresses induced by vibratory motion, in which cases the number of stress cycles are rapidly accumulated. For example, at 100 cps, 100,000 strain cycles, (a significant figure in the endurance limit of metals) can be accumulated in about 16 min. Thus, even though in normal operation the frequency of the exciting force may coincide with the resonant frequency of the vibratory system only momentarily due to change in engine (or other) speed, this period of time is easily accumulated.

The challenge in this type of problem is to visualize the mechanism causing the fatigue: what is the source of the exciting forces, what are the important elements of the vibratory system, and how are the motions related to the fatigue observed? Needless to say, there are many developmental problems where the inverse viewpoint is assumed: determine the stress levels under a variety of operating conditions to determine whether a good design has been achieved. A good design is economical and one in which both deflections and stress levels are satisfactory.

Stress is determined by measuring strain with resistance-type or ceramic-type strain gauges and converting the observed strain to stress using the known elastic modulus. Many problems require the use of dozens of these strain gauges, the minute signals representing electrical facsimiles of the strain-time relation. These signals, like those from vibration pickups, are amplified and recorded on a multi-channel oscillograph. Frequently, vibration signals and strain signals are recorded simultaneously in order to properly relate cause and effect.

Thus, the engineer working in this 3-cornered area finds himself trading blows with noise, its measurement, and its control. The engineer distinguishes between

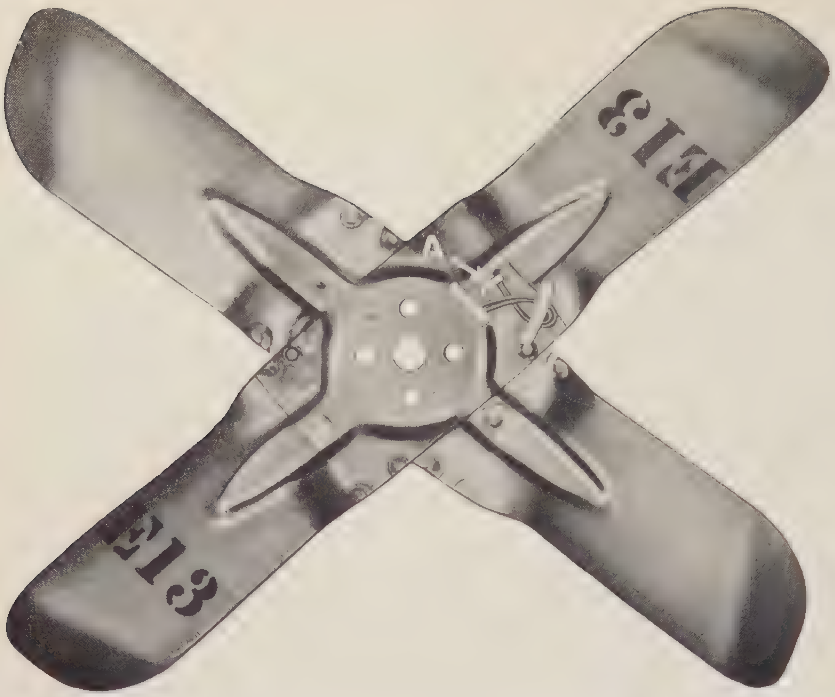
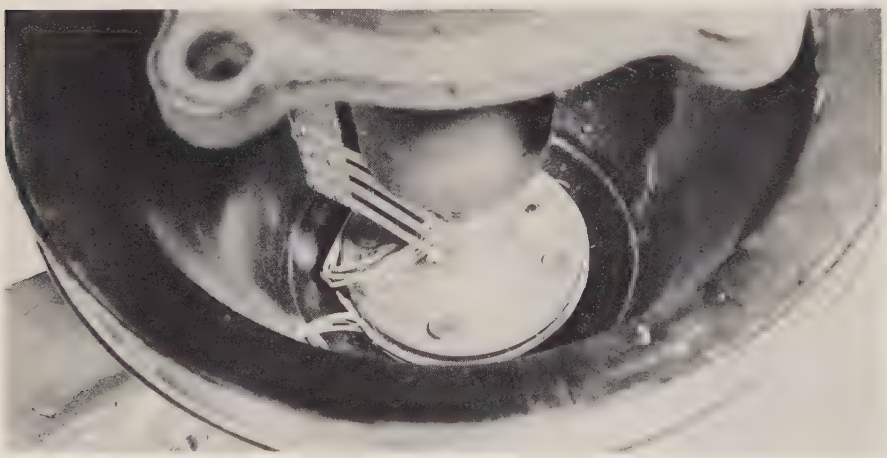


Fig. 8—A vibration which led to a stress problem and ultimately failure is found in an automotive engine cooling fan design. Failure occurred at the root of the fan blades, and it was suspected that a resonant vibratory condition was causing the repeated stresses leading to fatigue. To determine the resonant frequency at operating conditions, thin wafers of polarized barium titanate were applied as the strain sensitive gauge, visible as a small white rectangle marked **A** (above). These wafers were connected to a 4-circuit slip-ring on the fan shaft (below). The solution to the problem lay in raising the critical speed out of the operating range. One method of reaching this solution lay in spotwelding a partial blade section to the standard blade (above). In this way, the natural frequency was raised and mechanical damping was increased.



the 3-dimensional field problem and its simpler lumped-constant cousin. He finds himself in the ring with vibration, vibration-mount isolation theory, the distributed-constant field problem, and the lumped-constant vibration system. He likes to think of acoustical or electrical circuit damping in terms of Q but finds that it bears a known and useful relationship to the percentage of critical damping and decrement as applied to lumped mechanical systems. Having bridged the gap to vibration systems, sooner or later he becomes involved in stress problems caused by vibrations. He strengthens his hand by a camaraderie with mechanics and strength of materials and inevitably finds himself back in the starting corner with sound.

While developing skills in these areas, he is unobtrusively but surely building a strong and invaluable understanding and appreciation for the silent partners in the endeavor:

- Transducers and associated electronic instrumentation without which only a few of the more simple problems could be tackled
- The importance of the characteristics of microphones; the characteristics of vibration pickups and their natural frequency, response characteristics, and damping
- The importance of the natural frequencies and damping of magnetic oscillograph galvanometers and their relation to sensitivity and response.

Practical Applications Found in Chassis, Crankshaft, and Fan Blade

Having dwelt sufficiently on generalities, specific examples of the 3 types of problems introduced by the relationship of vibration, noise, and stress can now be considered.

Vibration

An example of a vibration discomfort problem is found in a recent experience concerning the vertical beaming vibration of a truck chassis (Fig. 6). This vibration was excited by rough roads and intensified by the action of a vibratory motion of the suspension, called wheel hop. The frequency of vibration was 11 cps and for this reason would not be expected to pose a noise problem. The mode of the vibration was established by using several self-generating seismic vibration pickups disposed along the frame side rail and orientated for sensitivity in a vertical direction. These vibration signals were recorded simultaneously on a multichannel recording oscillograph. Analysis of the oscillogram indicated a vertical beaming of the frame and the cab and body mounted thereon, with maximum displacement amplitude at the center of the span. The cure was to stiffen the frame in vertical flexure by increasing the sectional moment of inertia. This is an excellent example of a lumped-constant system (the "unsprung" weight of the axle on the springiness of the tires) contributing to the severity of a distributed-constant system (the truck chassis). The resonant frequencies were essentially coincident.

Vibration—Noise

An example of this involves the vibration of the flywheel in a tilting mode on the flexibility of an 8-cylinder crankshaft (Fig. 7). The frequency of the vibration was 205 cps. The exciting forces were provided by the explosion forces of the 8 cylinders, occurring 4 times per crankshaft revolution. This was a resonant vibration, that is, a harmonic driving force tuned in at a given engine speed to the resonant frequency of the mechanical vibration system.

This problem, unlike the vibration discomfort problem just discussed, made its presence known by the sound heard, and it is a good example of the dependence of the vibration techniques required to solve a noise problem. It is interesting to observe that a microphone, a sound sensing device, was used only at the start of the problem to determine the frequency of the sound. Thereafter, the problem was handled as a vibration problem. In no other way could any progress have been made on this sound problem. It should be pointed out that the frequency observed from a stationary reference point differs from that observed on the rotating system, if the vibratory pattern moves with the rotating system as in this instance.

Vibration—Stress

A fan blade design is an example of a problem in which the vibration leads ultimately to failure because of fatigue.

A fan blade assembly consisting of 2 full blades, crossed at 72° and riveted, was failing due to bending vibrations inducing large stresses at the root of the blades. The exciting forces were of aerodynamic origin, caused by blade passage past nearby obstructions to air flow. As in many such problems, fatigue failure was suspected to be due to operation in a resonant vibratory condition. In this situation, many cycles of repetitive stress were accumulated rapidly; further, the resonant condition was capable of inducing these stresses.

To determine the resonant frequency under operating conditions, thin wafers of polarized barium titanate were applied near the root of an experimental blade (Fig. 8 top). These wafers were connected to slip rings (Fig. 8 bottom). The resonant frequency was found to be 90 cps at a fan speed of 45 rps (2,700 rpm). Thus, due to the operating environment, the blade received 2 exciting pulses per revolution.

The answer to the problem lay in raising the critical speed out of the engine operating range so that the blade operates in the "stiffness-controlled" region. The frequency may be raised either by increasing the thickness of the full blade or by sandwiching 2 blades together in the hub area (Fig. 8 top). The significant stiffness resides in the root of the blade, and the significant mass at the tip. While it is true that raising the resonant frequency by any means is helpful, it is more helpful to maximize stiffness and minimize mass. In the stiffness-controlled range, that is, at exciting frequencies considerably below resonance, the dynamic deflection is controlled largely by the stiffness constant, and this effect is reasonably independent of the value of the natural frequency and additive to the effect gained by raising the natural frequency per se. In addition, the increased mechanical damping due to the rubbing friction as the blade is flexed is of some help even in the stiffness-controlled frequency range. This, of course, becomes increasingly important should the fan approach the (new) resonance due to high speed overrun of the engine while the vehicle is going down grade.

Conclusion

These examples illustrate the important interdependence and interrelationships between noise, vibration, and experimental stress analysis. The interdependence is evident not only in the instrumentation used for all, but also in the similarity of the vibrating systems indicated by the analogous differential equations of motion.

Furthermore, a vibrating system is quite likely to lead to either a noise problem or a stress problem so that for still another reason the attack on problems in these fields can best be done by a single, integrated engineering group.

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C. F. Kettering Award Established by Six Engineering Societies

The *Charles F. Kettering Award* has been established under the joint sponsorship of 6 national engineering societies. Charles F. Kettering was the first recipient of the award bearing his name at ceremonies of the 1956 fall meeting of the American Institute of Electrical Engineers. Mr. Kettering is a director of General Motors and former vice president and general manager of the Research Laboratories Division (now the GM Research Staff).

The award is sponsored by the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the American Institute of Chemical Engineers, and the Society of Automotive Engineers. It is expected that the award will be made annually to an outstanding engineer "for creative accomplishments for the benefit of mankind, including discovery, invention, improvements in designs or processes within the relationship of materials and energy."

The idea of establishing the award came from 2 long-time friends of Mr. Kettering, namely E. G. Bailey, founder and chairman of Bailey Meter Company and former vice president and director of Babcock and Wilcox Company, and A. A. Potter, Dean Emeritus of Purdue University.

Mr. Kettering, holder of numerous awards and honorary degrees throughout the world for his contributions to scientific research, is a 1904 graduate from The Ohio State University with a degree in electrical engineering. Early in his career, he organized the Dayton Engineering Laboratories Company from which came the development of the automotive electrical starting, lighting, and ignition system.

Believing that research should be a cooperative effort involving the integrated talents of all types of engineers and technicians, Mr. Kettering has used his personality, drive, and guiding hand in directing the research programs leading to the development of many important inventions and discoveries, among them tetraethyl lead, Freon, and a new type of 2-cycle Diesel engine.

Special Materials for Unusual Ball Bearing Applications

By **WILLIAM BLINDER**
New Departure Division

Ball bearings are being called upon to operate under increasingly severe conditions of speed, load, temperature, and corrosive atmospheres. Under these conditions the standard bearing materials often are incapable of meeting the requirements of life or reliability, or both, with the result that new materials must be found. As part of a continuing study, New Departure Division engineers have conducted a testing program to evaluate various bearing materials. From this study has come a number of recommendations which are helpful to the designer solving the problems created by the newer, more stringent requirements of bearings.

An adequate bearing material often is the key to the final design of today's unique machines

As a result of recent developments in machine tools, aircraft engines, aircraft accessories, and nuclear power plants, the ball bearing industry is faced with a number of interesting, though complicated, problems. New designs of equipment are continually demanding smaller bearings to carry heavier loads at higher speeds and higher temperatures and, in some cases, in a corrosive and/or non-lubricating medium. Although the ball bearings in a machine are generally the components most free from trouble, the trend has progressed to the point where, in some cases, machine developments must await bearing developments.

The common type of ball bearing consists essentially of a number of balls riding in race grooves ground into concentric rings and generally spaced by a separator, or cage, (Fig. 1). Basically, the ball bearing is a reliable means for carrying a heavy load at high speeds with low friction and minimum lubrication. Despite the apparent simplicity of the ball bearing, however, very few materials have escaped consideration for possible ball bearing usage under difficult operating conditions.

This paper will not attempt to describe the complexities which arise in the design of this apparently simple mechanism or the factors other than material which determine whether an application will be successful. However, an understanding of the general requirements of bearings is necessary in any discussion of material.

Standard Operating Conditions

Even under lightly loaded conditions, Hertz contact stresses between balls and races generally exceed 100,000 psi and in many cases are as high as 500,000 psi and above. Thus, it is evident that even for bearings operating under "normal" conditions the excellent life records of ball bearings are attained only by the most careful attention to material quality.

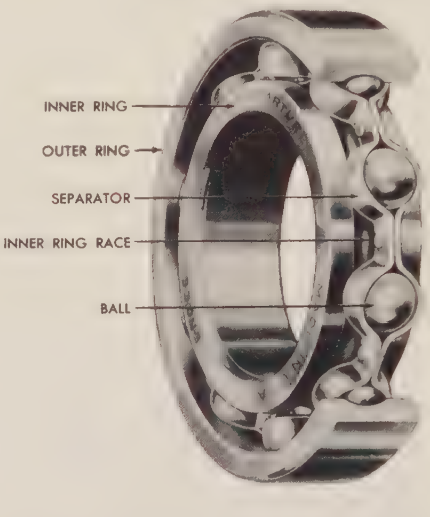


Fig. 1—This sectional view shows the construction of a typical standard, deep-groove, single-row ball bearing.

Generally, for the majority of applications, the required speeds, loads, and temperatures are low enough so that no particular problems are imposed. Under such conditions ball bearings are relatively insensitive to type or quantity of lubrication and may be satisfactorily lubricated by oil jet, splash or mist systems, grease or, in some cases, by an initial light coating of oil which lasts the life of the unit.

Ball bearings, however, are sensitive to mounting fits and alignment, dirt, and other contaminants, and these factors also must be considered for satisfactory service.

Standard Materials

The materials most generally used for ball bearings are 2 high-carbon, high-chromium steels: AISI modified 52100 for rings (Fig. 2), and AISI modified 51100 for balls. Basically, these are 1 per cent chromium, 1 per cent carbon electric-furnace steels used in the fully hardened condition tempered to 62-64 Rockwell C hardness. They are among the *cleanest* of the commercially available high-tonage materials. This cleanliness, which has come about over the years largely at the insistance of ball bearing manufacturers, is extremely important since *non-metalic inclusions*, which are present in some degree in all metals, are known to be a major cause of bearing fatigue failures. This is thought to be due to the fact that these inclusions (for example, oxides, silicates, aluminates, and sulphides) act as voids which will produce stress concentrations if located in the load track of the races or on or near the surface of a ball.

Aside from the high-carbon, high-chromium steels, the 2 other most common materials in use are AISI 440C stainless steel for mildly corrosive conditions and AISI 5120, a high quality case hardening steel for bearings where a ductile core is necessary for toughness or high impact strength.

Ball bearing separator, or cage, materials for the usual operating conditions are generally 1010 steel or 430 stainless steel of stamped-ball controlled design for low- or normal-speed conditions and either fabric base phenolic or bronze ring controlled separators for high speed conditions (Fig. 3).

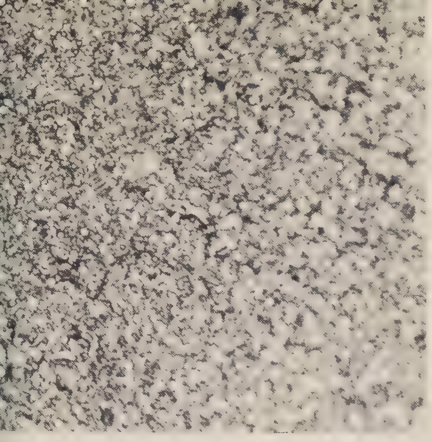


Fig. 2—This photomicrograph (X1000) shows the normal martensitic structure of AISI 52100 ball bearing steel.

Material Evaluation Methods

As already mentioned, difficult bearing applications are concerned with the following operating conditions: (a) heavy loads, (b) high speeds, (c) high temperatures, (d) poor or no lubrication, and (e) corrosive environments. These conditions occur either singly or, as is more generally the case, in combination. Examples of these conditions are readily found in jet engine bearings which are subjected to operating conditions (a) through (d), inclusive, and in nuclear energy bearings which are generally subjected to conditions (c), (d), and (e). Despite these difficult conditions, new, even more stringent standards of performance are required because of the danger to life and property and the inaccessibility for repairs and maintenance.

In many cases requirements cannot be met by standard bearing materials or available knowledge and considerable developmental work must be performed in order to meet the required conditions. At New Departure Division a testing program has been conducted to aid the search for improved bearing materials. The major phases of this materials testing program are as follows:

- Gall or compatibility
- Hot hardness and creep strength
- Bearing performance
- Bearing fatigue
- Bearing wear.

It must be emphasized that this testing program is a continuing activity and that considerable work is required before all phases are complete and results checked against actual service conditions. Since the problems involved are in many cases relatively new, complete solutions are not available.

Gall or Compatibility

Galling, which may be defined as surface damage due to sliding of one material over another and is characterized by metal transfer or pickup, becomes increasingly important as speeds, loads, and temperatures increase. The galling characteristics of promising material combinations at temperatures up to 1,000° F are evaluated in a special testing machine (Fig. 4). In this machine one of the test materials is made into a spherical roller and mounted on a spindle within an insulated temperature-controlled housing. The other material is made into a flat plate sample which is mounted onto a sample holder and loaded against the spherical roller by means of a deadweight system acting through a 4-bar linkage. The galling characteristics test can be run at various load, speed, temperature, and lubrication conditions to evaluate surface damage of various combinations of materials at elevated temperatures.

Hot Hardness and Creep Strength

The material properties of hot hardness and creep strength are currently considered as the best measure of the load carrying capacity of ball and ring materials and the limiting speed of separator materials for elevated temperatures. Information on these properties, therefore, is required for intelligent material selection and proper bearing design. Unfortunately, this information is not generally available on the materials which are of interest, and steps are being taken to obtain this vital data.

Bearing Performance

Depending on the results of the gall test and other material properties, bearing components may be made of the particular materials being investigated and run in a test machine to evaluate actual performance.

In one type of machine used, the test bearing is mounted outboard on a water cooled, ball bearing-mounted spindle within an insulated temperature controlled enclosure (Fig. 5). This machine is capable of testing bearings up to 40 mm bore at speeds up to 25,000 rpm, temperatures up to 1,000° F, and thrust or radial load in any combination with either grease or oil-mist lubrication. Bearing torque and bearing temperature are continuously recorded during a test. Both a mechanical and an electrical stop are provided, thus allowing testing to be discontinued at first evidence of bearing troubles. This machine, therefore, checks material compatibility results obtained by gall testing and determines bearing performance characteristics for bearings made of special materials, as well as design variations on the basis of heat generation, torque, and ability to operate under simulated "lubrication failure" conditions.

Bearing Fatigue

Standard specimen endurance test results on Moore rotating beam fatigue tests are, at best, only indirectly related to ball bearing fatigue. It has been found necessary, therefore, to determine fatigue or endurance characteristics by running tests on actual bearings of the test material. This is done by maintaining banks of fatigue test machines (Fig. 6). At present, due to oil limitations, endurance tests are not run at temperatures above 400° F. However, as improved high-temperature lubricants become available, test temperatures will be increased.

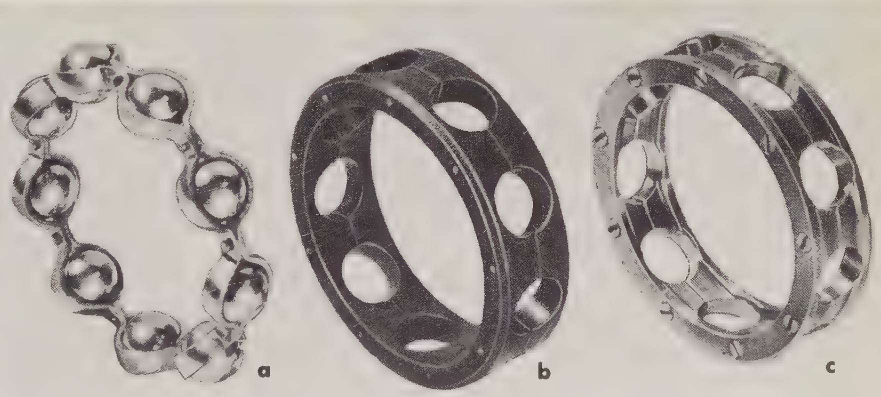


Fig. 3—The 3 most common types of ball bearing separators are: (a) ribbon, (b) non-metallic, and (c) bronze.

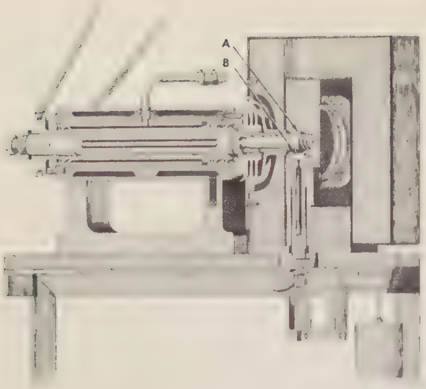


Fig. 4—This cross-sectional view of a specially designed, high-temperature gall-test machine illustrates how material combinations are evaluated for degree of damage due to sliding of one material over another under various conditions of speed, load, temperature, and lubrication. One of the test materials *A* is spherically made to represent a ball, and the other test material *B* represents either a separator or a race. Material *B* is loaded against test material *A* by means of a dead-weight system acting through a 4-bar linkage.

Bearing Wear

Although wear is not a factor in normally lubricated bearings, it exists in many nuclear applications where speeds are low, loads are light, and bearings must operate under conditions where lubrication is not possible—that is, immersed in water or operating unlubricated in an inert atmosphere. Temperatures may reach 1,600° F. Under these conditions, providing design and materials are correct, bearings wear gradually, and failure is caused due to either loss in positioning of the machine or to the balls decreasing in size to the point where they fall out of the rings. A machine has been developed to allow testing of bearings of special materials and design when operating under such conditions.

In addition to the above, many specialized tests are run for specific customer applications, very often on the customer's own equipment.

Discussion and Recommendations

In general, ball and ring materials should have certain definite properties, the relative importance of one or another depending on the application. As in most other fields, compromises usually must be made to obtain a suitable combination of properties. The following properties are desirable in ball and ring materials:

- High endurance under fatigue loading
- High impact strength
- Hardness high enough at the operating temperature to carry the applied loads without permanent deformation
- Good gall and wear resistance with the lubricating medium used
- Corrosion resistance
- Dimensional stability
- Uniformity and freedom from segregation
- Reasonable cost of material and processing.

For unusual applications it is possible to classify bearing materials into 2 general groups: (a) those materials for use under high-temperature conditions and (b) those materials for use where a corrosion resistant and/or non-magnetic requirement exists. In many cases a combination of the 2 requirements must be met.

High-Temperature Applications

While today there are only a few production applications for bearings operating above 450° F, there are a number of designs being developed which will require bearings to operate above this temperature. The standard 52100-51100 steel bearings stabilized for elevated temperature operation have been successfully used at temperatures up to and, in some cases, above 450° F. However, at temperatures above 300° F, structural and dimensional changes occur due to transformation of martensite, the rate

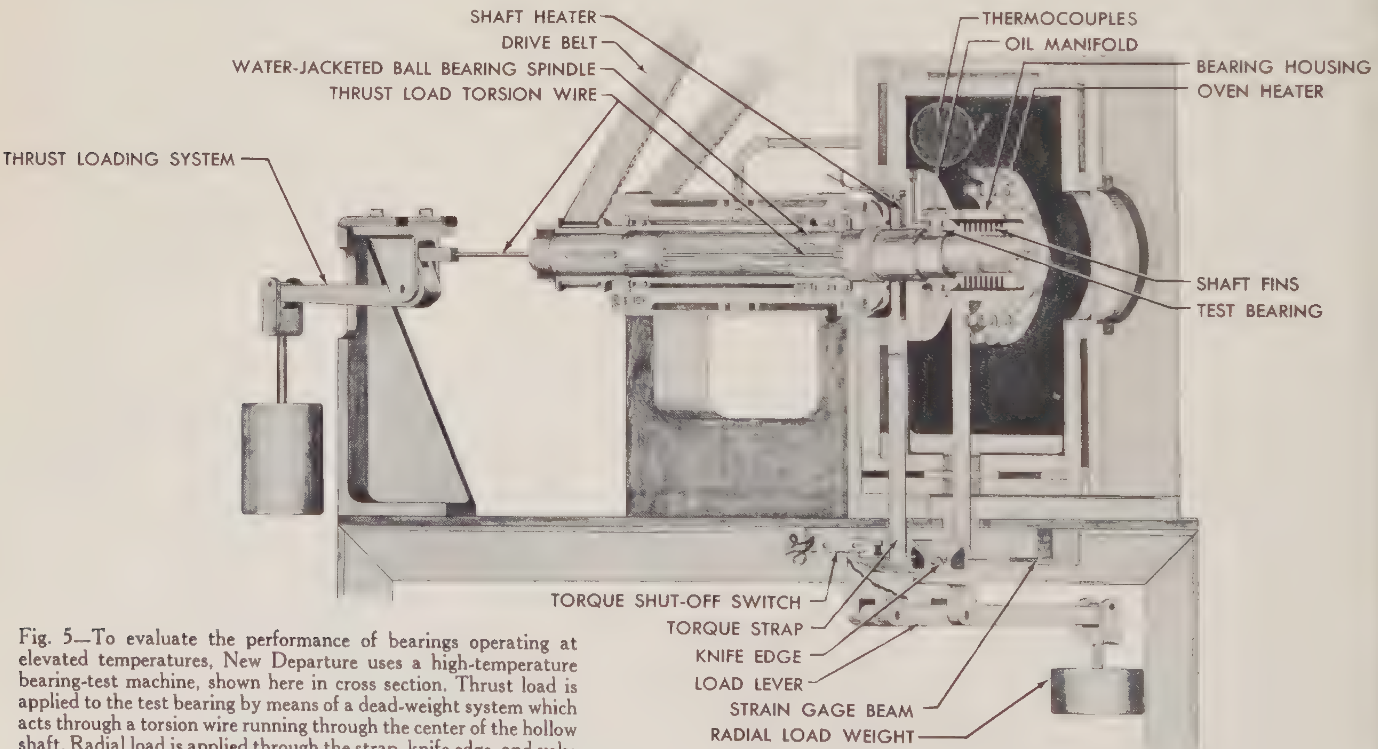


Fig. 5—To evaluate the performance of bearings operating at elevated temperatures, New Departure uses a high-temperature bearing-test machine, shown here in cross section. Thrust load is applied to the test bearing by means of a dead-weight system which acts through a torsion wire running through the center of the hollow shaft. Radial load is applied through the strap, knife edge, and yoke system. This allows measurement of bearing torque during operation, since bearing torque is transmitted to and resisted by the cantilevered strain gauge beam mounted below the table.

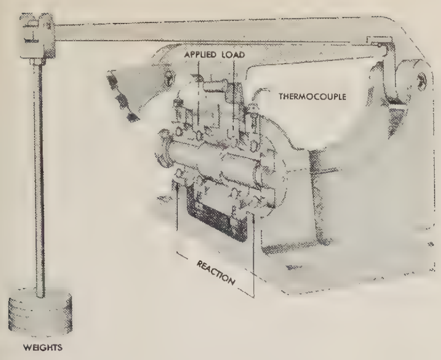


Fig. 6—This cross-sectional view shows one station of a multi-station bearing-fatigue test machine used to evaluate endurance characteristics of ball bearings. Although the view shows only the application of radial load, thrust loads also can be applied to the center bearings by means of a calibrated set of Belleville springs (not shown). The thermocouples are used to measure bearing temperatures under various operating conditions.

of change increasing with temperature. As a result bearing capacity and life are decreased.

Materials having the greatest promise for temperatures up to 900° F to 1,000° F are the high-speed tool steels. These high alloy steels have good hot hardness, dimensional stability, and high temperature strength because of their tungsten, cobalt, molybdenum, and vanadium contents in various properties depending on the alloy. However, a basic disadvantage of this class of materials is that, as commercially made, they are *dirty*—that is, they contain a high content of nonmetalic inclusions which, as already discussed, lead to early bearing failures.

There has been considerable progress made in eliminating this undesirable feature. Properly controlled processing techniques are capable of producing high-speed tool steels which are cleaner than "bearing quality" 52100 steel. For example, commercial, air-melted steels and properly controlled vacuum-melted steels of the same analysis show a marked difference in inclusion content (Fig. 7).

Endurance test results of ball bearings made of these materials show a marked improvement both in average life and in percentage of early failures due to the use of the *clean* steel. However, it must be cautioned that vacuum melting in itself is no guarantee that acceptable quality will be obtained. Rigid inspection procedures, therefore, must be continued.

Non-Magnetic and Corrosion-Resistant Applications

Non-magnetic bearing materials are occasionally required for applications where the magnetic properties of conventional bearing materials may disturb equipment operation or where an accidentally magnetized bearing may radiate a radio signal which would interfere with nearby radio operation or, in military applications, disclose position to an enemy.

Corrosion resistant materials are required for operation in pressurized water at temperatures up to 600° F, in air or inert gas at temperatures up to 1,600° F, and in corrosive gases at various temperatures. There also are many bearings utilized in the food processing industry which must be corrosion resistant. These bearings, however, generally are subjected to less severe operating conditions.

Since, in the above cases, lubrication other than the operating medium is generally not possible, compatibility and wear resistance are important requisites. Cobalt chromium-base, nickel-base, and copper-base alloys have all been used for such appplications, in some cases with good results and in others with marginal results. Laboratory tests also have been run on materials such as sintered tungsten carbide, sintered chromium carbide, glass, sapphire, and graphite. Unfortunately, however, this latter group of materials has not performed well, at least at normal room temperature, generally due to their inherent brittleness.

The stainless steels, of course, constitute a very important group of materials in the corrosion-resistant field. Commercially, these are generally grouped into the hardenable types and non-hardenable types. Of the hardenable types, perhaps the best known is 440C stainless steel, which is a standard bearing material. The endurance characteristics of bearings made commercially of this material are generally adequate for most commercial applications. It must be remembered, however, that 440C stainless steel is magnetic and is stainless only when it is hard and polished. Since hot hardness of this material is poor, it is generally not recommended for temperatures above 500° F.

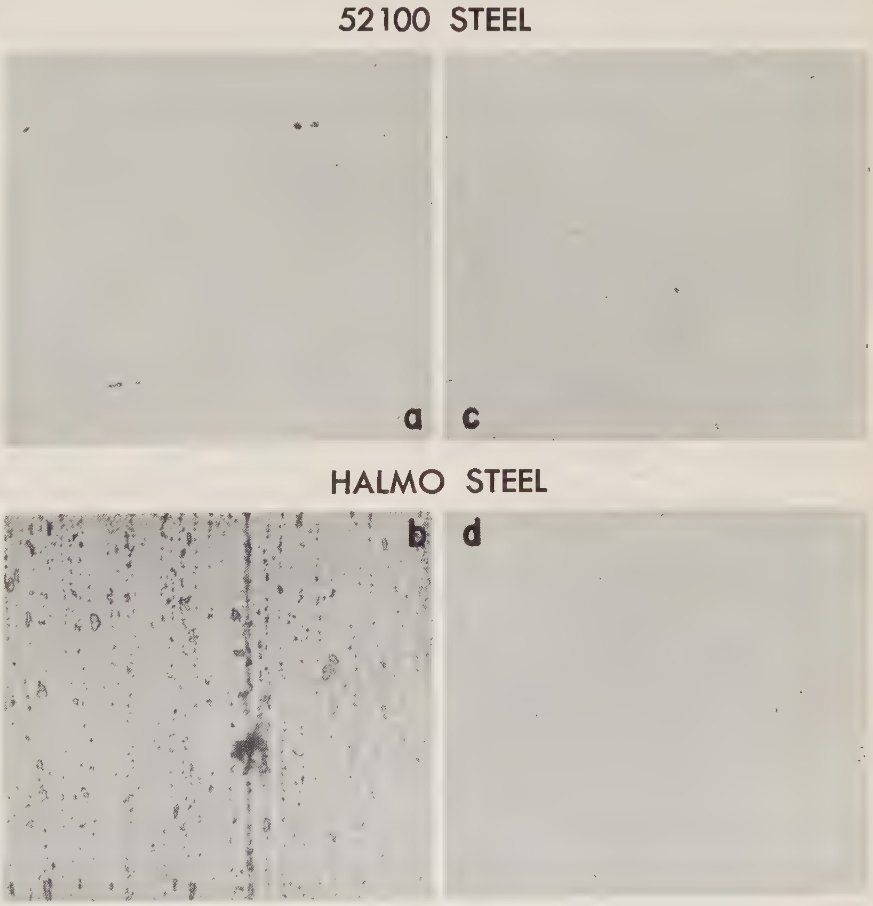


Fig. 7—These un-etched photomicrographs (X100) of polished specimens illustrate the difference between induction air-melted 52100 steel (a) and Halmo tool steel (b) and properly controlled vacuum-melted steels of the same analysis (c) and (d) respectively.

BALL BEARING MATERIALS

Ball and Ring Materials	Temp °F	Hot Hardness	Gall Rating	Oxidation Resistance	Magnetic	Bearing Fatigue	Comment
Bearing Quality Standard AISI 52100 and 51100 Steels	100	Excellent	Good	Fair	Yes	Excellent	Standard ball and ring material. Requires stabilization for use at temperatures above 300°F.
	300	Excellent	Fair	Fair	Yes	Excellent	
	500	Fair	Poor	Fair	Yes	Fair	
	700	Poor	Poor	Fair	Yes	Poor	
440C Stainless Steel	100	Excellent	Poor	Good	Yes	Good	Standard ball and ring material for use under mildly corrosive conditions. Martensitic stainless steel. Has good resistance to tempering but poor hot hardness.
	300	Excellent	Poor	Good	Yes	Good	
	500	Fair	Poor	Fair	Yes	Fair	
	700	Poor	Poor	Poor	Yes	Poor	
Vacuum-Melted, High-Speed Tool Steel (5% Cr, 5% Mo, 0.65% C)	100	Excellent	Fair	Fair	Yes	Excellent	Low critical alloy, high-speed tool steel. Has given excellent endurance life when tested at temperatures up to 400°F. Used in jet engine bearings.
	300	Excellent	Fair	Fair	Yes	Excellent	
	500	Excellent	Fair	Fair	Yes	—	
	700	Good	Fair	Fair	Yes	—	
	1,000	Fair	Fair	Fair	Yes	—	
Air-Melted, High-Speed Tool Steel (5% Cr, 5% Mo, 0.65% C)	100	Except for fatigue strength, other properties are similar to those for the vacuum-melted steel above.				Poor	Same as above but, as commercially made, is too dirty for successful bearing usage.
Cobalt, Chromium, Tungsten Base Alloys	100	Good	Good	Excellent	No	Fair	Used in high-temperature corrosive applications. Exhibits excellent wear resistance.
	500	Good	Good	Excellent	No	Fair	
	900	Good	—	Excellent	No	Fair	
	1,200	Fair	—	Excellent	No	—	
Beryllium Copper	100	Fair	Good	Excellent	No	Fair	Used for low-temperature, non-magnetic, and/or corrosive applications. Retains high impact resistance at liquid-air temperature, thus used for such conditions.
Sintered Tungsten Carbides	100	Excellent	Good	Excellent	Yes	Poor	Not presently used as bearing material because of poor fatigue resistance.
	300	Excellent	—	Excellent	Yes	—	
	500	Excellent	—	Excellent	Yes	—	
	700	Excellent	—	Excellent	Yes	—	
Ceramics and Ceremets	Up to 1,600	Excellent	—	Excellent	—	—	This class of materials is being evaluated for extreme conditions.

Table I—This table summarizes the principal properties of ball bearing materials now in use and those materials being considered for use in critical applications.

SEPARATOR MATERIALS

Separator Material	Temp °F	Gall Rating	Oxidation Resistance	Magnetic	Comment
1010 Steel	Up to 500	Fair	Poor	Yes	Standard separator material for low-speed or non-critical applications.
Fabric Base Phenolic	Up to 275	Excellent	—	No	Standard separator material for high-speed bearings.
430 Stainless Steel	Up to 1,000	Poor	Excellent	No	Standard separator material for low-speed 440C stainless steel bearings.
17-4-Ph Stainless Steel	Up to 1,000	Poor in air	Excellent	Yes	Successfully used in high-temperature water applications. Has good wear resistance.
Iron Silicon Bronze	Up to 450	(1)	Excellent	No	Used for jet-engine applications, as well as other high-speed, medium-temperature bearings. (1) Gall rating ranges from good at 100°F and 300°F to excellent at 500°F.
S-Monel	Up to 1,000	Fair	Excellent	No	Has excellent high-temperature strength. Used for temperatures above the limits of iron silicon bronze.
Silver Plate	(2)	(3)	Excellent	No	Successfully used in many journal-bearing applications. (2) Provides good results in many difficult ball bearing applications at temperatures up to 350°F. (3) Gall rating ranges from excellent at 100°F and 300°F to poor at 500°F and 700°F.

Table II—This table summarizes the principal properties of ball bearing separator materials currently in use.

Conclusion

At present, the primary problem in the successful operation of bearings above a temperature of 450° F appears to be either:

(a) Development of a lubricant or lubrication system which can withstand these temperatures, or

(b) Development of a material or a combination of materials which can operate together with minimum external lubrication.

Many investigators are engaged in the development of high-temperature lubricants, and developments in this area are being watched carefully. In general, it may be said that the ball bearing industry can, and is, furnishing special bearings for use under conditions thought impossible only a few years ago (Tables I and II). However, it also is true that many customers' requirements cannot be met at present. A great deal of work remains to be done in devising solutions to specific customer problems and in increasing the understanding of the fundamental behavior of bearing materials.

Considerable progress has been made in ball bearing materials in recent years. Since, however, indications are that bearing requirements will continue to increase in severity in future years, the present program for evaluating new materials will remain in effect until complete solutions to the many problems involved are obtained.

Bibliography

Other related literature in this field includes the following:

Allan, R. K., *Rolling Bearings* (New York: Pitman Publishing Company, 1946; 2nd Edition).

Bowden, F. P., and Tabor, D., *Friction and Lubrication of Solids* (Oxford: Clarendon Press, 1950).

Roach, A. E., and Goodzeit, C. L., "Why Bearings Seize," *General Motors Engineering Journal*, Vol. 2, No. 5 (September-October 1955), pp. 25-29.

......, *New Departure Handbook*, Vol. 1, 23rd Edition (April 1955).

The Engineer in Patent Suits

By ROBERT L. SPENCER
Patent Section
Central Office Staff

A good team to inform the court: trial attorney, engineer, and patent attorney

THE defense team in suits for patent infringement usually includes a trial attorney who is in charge of the case, an engineer who is the technical expert, and the corporation or house patent attorney, if there is one. In addition, there may be a so-called "patent expert."

Preparing for a trial is essentially an investigative and educational procedure wherein the attorneys, engineers, and experts become familiar with the patent in suit and the accused structure and develop and become familiar with the defense material. The objective is to develop the best defenses and present them simply and directly so that a technically untrained person can readily understand and follow the argument of the trial attorney without undue effort. To achieve this result may require, in a complicated case, close screening of possible defenses with elimination of some for the sake of simplicity and understanding. This screening process necessitates careful analysis and study by both the engineers and attorneys in order that the attorneys may have a correct understanding of the technical aspects of the operation and function of the patented structure, the accused structure, and the defense material. At the same time, the engineers involved receive a clear picture of what the issues are and how these issues are to be met. By the time the defenses are determined, the engineers are thoroughly familiar with the patented structure, the accused structure, the issues, how the defense material applies to the issues, and why it is being used.

Engineering Facts Must Be Collected, Analyzed

By filing a suit for patent infringement, the patentee is saying, in effect, "You have used my invention—pay me." One of the most effective ways to counteract this charge is to show the Court that the accused device, or others like it, or the patented device was developed by the defendant before the plaintiff filed his application for his patent. Such a defense obviates any claim of "getting something for nothing" from the patentee. In addition, where it can be shown that the accused device was developed independently of the patentee, the distinctions between the patented and accused devices may be pointed out more effectually, and the defense is more readily accepted. To establish such a defense requires a thorough investigation of prior developments by the defendant, including not only the accused structure itself but any additional developments of like nature which may or may not prove to be helpful. Obviously this investigative phase is lengthy and difficult and requires expert technical assistance which can only be rendered by the engineers acquainted with the subject matter. In the course of the investigation, thousands of documents, such as drawings, purchase orders, and test reports, may have to be examined. It is only through close cooperation with the engineers involved that a clear picture of various pertinent developments can be obtained.

When the defense material has been collected, analyzed, and what is to be used has been determined, the problem is to present the defenses in such a clear and concise manner that they can be readily understood in a minimum of court time. This is usually accomplished through the use of large charts illustrating the patent in suit, the accused device, and the defense material. Here again the technical assistance of the engineer is required in order to insure accuracy of representation so that the charts may not be attacked for failure to truly illustrate the device they represent.

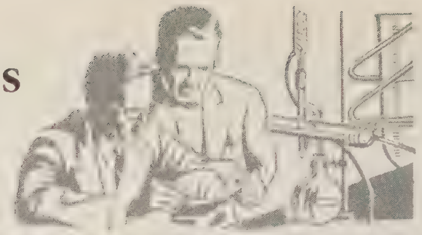
Most patent infringement suits are tried by a Judge without a jury, but in a few there is a jury in addition to the Judge. In either case, it must be remembered that neither the Judge nor jury will be familiar with the subject matter, and the chances are that neither will be technically trained. Therefore, the manner in which the defenses are presented may spell the difference between success and failure, and, consequently, it is important not only that they be presented in a technically accurate fashion but also that they be presented as simply and clearly as possible. The charts are the tools by which the trial attorney is able to present his case in a minimum of time and with clarity. To prepare them so that they tell their story simply, clearly, and accurately presents a real challenge to the engineers, as well as the lawyers.

Charts Aid Technical Understanding by the Court

Throughout the course of the trial the charts are before the Judge and the jury, and, when well done, they may be very effective. Charts do not constitute evidence, and evidence, of course, must be presented. However, the evidence as illustrated by the charts receives a great deal of attention and may create important impressions. This was well illustrated in a recent suit wherein the plaintiff presented his case by the use of charts which were obscure and hard to follow. At the conclusion of plaintiff's case, neither the Judge nor the jury understood the patented device, the accused structure, or the issues involved. The jury was clearly bored and mentally fatigued. Fortunately, the defendant's charts had been colored and otherwise prepared so that the various parts of the patented device and accused structure could be seen and understood easily. The jury learned about the case from the defendant rather than the plaintiff. After 3 weeks of trial time, the jury required 20 minutes to return a verdict for the defendant. It was largely a result of the careful and extensive preparation and assistance on the part of the engineers connected with the defense of this suit that the defendant's case was presented clearly, understood, and accepted by the jury.

In summary, the role of the engineer in a suit for patent infringement is an important one. It includes assisting the attorney to find the evidence, studying and analyzing the patent in suit and its relation to the accused structure, giving technical advice to the attorney throughout the development of the defenses, rendering technical assistance in preparation of charts and other exhibits used in the court room, and testifying at the trial.

Notes About Inventions and Inventors



Contributed by
Patent Section
Central Office Staff

On this and the following pages are listed some of the patents granted to General Motors prior to May 31, 1956. The brief patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each patent.

Patents Granted

- **Duane R. Crumb,** *Rochester Products Division, Rochester, New York, for a Key-Controlled Cylinder Lock, No. 2,733,590, issued February 7.* This patent is for an extremely difficult to pick, key-operated pin-tumbler type lock giving a large number of combinations using tumblers rotatable in a sleeve and placed in 3 groups of 3 each radially positioned at 90° or 120° on both sides of the top to present 9 tumblers in all at 3 levels.

Mr. Crumb has been a senior project engineer with Rochester Products since 1951, working on locks and cigarette lighters. He joined the Division in 1939 after receiving the B.S.M.E. from University of Rochester. His work on locks has resulted in 2 patents.

Continued from page 47

Engineers are busy people who have pressing problems which at any given moment may appear more important than "digging up their past mistakes." Becoming involved in a suit for patent infringement may be looked upon initially as an unnecessary or at least an unwelcome burden by the engineer. However, as the defense picture is pieced together and the preparation for trial is completed, the engineer who contributes his time and efforts may well be proud of an important job well done. The giving of testimony during the trial is an interesting and unusual experience for most engineers. At the conclusion of a successful defense, a verdict for the defendant frequently is as much a source of satisfaction to the engineers involved as it is to the attorneys, for without the engineers' capable assistance, success could not be achieved.

- **C. B. Wright** *and* **John F. Haines,** *Aeroproducts Operations of Allison Division, Dayton, Ohio, for a Low-Density Propeller Blade, No. 2,734,586, issued February 14.* This patent is for a propeller blade having a box-like hollow structure of sheet metal struts with an airfoil section of skin made of a pair of spaced imperforate sheets disposed on either side of a filling of corrugated or other low-density material providing a blade that will stand rotative stresses without setting up destructive vibration.

Mr. Wright is chief engineer of aircraft products of Aeroproducts. In 1938 he received the A.B. from Wittenberg College and joined Engineering Products as a design draftsman on propellers. In 1940 this organization became a part of GM, and he has since been associated with all of Aeroproducts' propeller designs.

Mr. Haines is no longer with the Division.

- **Richard A. Hirsch,** *Aeroproducts Operations of Allison Division, Dayton, Ohio, for a Propeller Torque Unit Construction, No. 2,734,587, issued February 14.* This patent is for coupling between a servo-motor propeller torque unit and a hollow root portion of a propeller blade establishing rotative driving relation using a split indexing ring having selective splined engagement with the outside of a cylinder of the torque unit and the inside of the blade root portion.

Mr. Hirsch is a project engineer with Aeroproducts, having joined the Division in 1944. His current work concerns the design and development of the propeller for use with the Allison 501-D13 turboprop engine for the Lockheed "Electra," the first U.S. built commercial turboprop powered aircraft.

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

- **Arthur J. Schutt** *and* **Charles F. Whitmore,** *Harrison Radiator Division, Lockport, New York, for a Thermostat for Engine Cooling System, No. 2,735,619 issued February 21.* This patent relates to a bellows thermostat mounting which is adapted to dampen bellows vibration.

Mr. Whitmore has been a project engineer since 1947, having joined Harrison Radiator in 1934. His current work concerns automotive air conditioning. Previous projects have included the development of aviation radiators and heater control valves.

Mr. Schutt is now retired.

- **Charles S. Bailey,** *Harrison Radiator Division, Lockport, New York, for a Thermostatically Operable Valve Mechanism, No. 2,735,620, issued February 21.* This patent relates to a heat-sensitive valve adapted for use in an engine cooling system comprising a radiator having a pressure cap. The valve serves to prevent circulation of coolant until the coolant reaches a predetermined temperature.

Mr. Bailey is a project engineer, supervising design and development of thermostats. He joined Harrison Radiator in 1936, after receiving the B.M.E. from Clarkson College in 1936. His work on thermostats, pump seals, and pressure caps has resulted in 4 patents.

- **W. Murray Kennedy,** *GMC Truck and Coach Division, Pontiac, Michigan, for a Hydraulic Governor, No. 2,736,305, issued February 28.* The invention provides a hydraulically operated governor for an internal combustion engine and employs the oil pump of the engine as a fluid pressure source and has a mechanical driving means for a speed valve in the governor.

Mr. Kennedy is an engineer working on development of gas engines and adaptation of Diesel engines to trucks and coaches. He joined GMC Truck and Coach in 1946, having been associated with GM since 1926. He received the B.A. in science in 1923 from University of Toronto.

- **Oliver K. Kelley,** *GM Engineering Staff, Detroit, Michigan, for a 3-Phase Turbine Drive, No. 2,737,061, issued March 6.* This patent relates to a transmission incorporating a twin turbine torque converter, compound planetary gear sets, and a direct drive clutch.

Mr. Kelley has been engineer-in-charge of the Transmission Development Section, Engineering Staff, since 1940. He received the B.S.M.E. and M.S.M.E. from Chicago Technical College and took special courses in automotive engineering at Massachusetts Institute of Technology. His work on the development of automatic transmissions has resulted in 24 patents.

- **Charles H. Frick** *and* **Ralph J. Rays,** *Detroit Diesel Engine Division, Detroit, Michigan, for an Altitude Compensated Pneumatic Governor, No. 2,737,166, issued March 6.* This invention relates to an altitude compensating mechanism for a variable speed, pneumatic-type, engine governor.

Mr. Frick has been a senior project engineer since 1952, having joined Detroit Diesel Engine in 1942. He is in charge of design and development of governors and controls for Detroit Deisel engines. Iowa State College granted him the B.S. degree in 1934.

Mr. Rays is no longer with the Division.

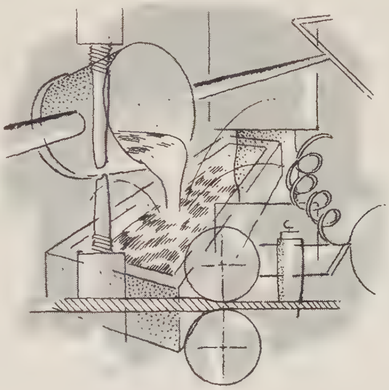
- **Henry H. Harada,** *AC Spark Plug Division, Flint, Michigan, for a Quick Reset Wheel Assembly, No. 2,737,345, issued March 6.* This invention relates to an odometer wheel assembly utilizing a spiral spring element assuring positive annular relationship between the wheel and its shaft, as well as smooth ratchet action for resetting the odometer.

Mr. Harada has been a senior designer in the Engineering Department since 1946, having joined AC Spark Plug in 1926 as a draftsman. His work on odometers, remote electrical-drive units, directional signals, and gearless-type pressure gauges has resulted in 8 patents.

- **Glen E. Brookbank,** *GMC Truck and Coach Division, Pontiac, Michigan, for a Door Latch, No. 2,737,406, issued March 6.* This invention pertains to a snap action lock for use on a bus luggage-compartment door lid and is automatically released by pulling on the luggage-compartment door handle.

Mr. Brookbank is a foreman in the Engineering Department at GMC Truck and Coach, having joined the Division in 1929 as an apprentice. His work entails supervision of the fabrication, assembly, and development of new coach models.

- **Francis E. Smith** *and* **Glen R. Urquhart,** *Fisher Body Division, Detroit, Michigan, for a Weatherstrip for Vehicles, No. 2,737,412, issued March 6.* This invention discloses a sealing weatherstrip for a frameless door and includes angular arms joined by a web which is engaged by the top of the window when the door is closed. The web flexes, pulling one arm down to provide an awning over the top of the window.



Mr. Smith has been senior staff assistant to the chief draftsman in the Design and Drafting Section of the Engineering Department since 1953, having joined Fisher Body in 1932. He was granted the B.S. degree in business administration in 1930 from University of Detroit and has supplemented his education with engineering courses.

Mr. Urquhart is no longer with the Division.

- **James H. Guyton,** *Delco Radio Division, Kokomo, Indiana, for a Signal-Seeking Tuner Circuit, No. 2,737,581, issued March 6.* This patent relates to a relatively simple and inexpensive signal-seeking tuner control for a radio receiver.

Mr. Guyton is assistant chief engineer, electrical, having joined Delco Radio in 1937. His work concerns development and production of automobile radios. He was granted the B.S.E.E. in 1934 and the M.S.E.E. in 1935 from Washington University, St. Louis, Missouri.

- **Verlos G. Sharpe,** *Frigidaire Division, Dayton, Ohio, and* **Louis Gelfand,** *GM Styling Staff, Detroit, Michigan, for a Refrigerating Apparatus, No. 2,737,781, issued March, 13.* This invention relates to a refrigerator having means for camming a slidable door into sealing engagement with door opening.

Mr. Sharpe is section engineer in the Household Engineering Department, having joined Frigidaire in 1948. He received the B.S.M.E. from Purdue University in 1948. From his work on household refrigeration 3 patents have issued.

Mr. Gelfand is a project engineer at the Styling Staff, where he is currently working on developmental engineering for the Kitchen of Tomorrow. He studied engineering at Wayne State University. As a result of his work 4 patents have been issued in the field of automotive and industrial appliances.

- **John W. Dyer,** *Delco-Remy Division, Anderson, Indiana, for a Magnet Motor for Sound Signals, No. 2,740,958, issued April 3.* This invention relates to a horn wherein an electromagnet carried by the horn back shell has a U-shaped frame and a T-shaped armature arranged such that all of the flux passing therebetween will have a useful component.

Mr. Dyer has been a research engineer since 1946, having joined Delco-Remy in 1937 as a draftsman. He attended Purdue University and Tri-State College, receiving the B.S. degree in electrical engineering in 1941.

- **Paul J. Pazitney, Jr.** *and* **Orville C. DeWeese,** *Inland Manufacturing Division, Dayton, Ohio, for an Extruding Machine, No. 2,738,549, issued March 20.* This patent relates to a method of extruding strip material from a rubber-like stock. A multiple die head includes control valves for each die orifice to balance flow of stock from each die.

Mr. Pazitney is an extrusion die maker at Inland Manufacturing, where his work concerns rubber and plastic extrusion of dies for production and experimental products. He joined the Division in 1933. His work in rubber extrusion has resulted in 2 patents.

Mr. DeWeese is an extruding die foreman at Inland Manufacturing, where his work concerns rubber extruding die making. He was employed by the Division in 1936 as an inspector and assumed his present position in 1947.

- **Harry C. Doane,** *Buick Motor Division, Flint, Michigan (now at GM Engineering*

Staff), *for an Illuminated Dial Device, No. 2,738,756, issued March 20.* This invention relates to a dial for indicating an automotive transmission setting and includes a lens movable with a shifting lever and positioned to transmit light received from a dial fixed to a steering column.

Mr. Doane was appointed assistant to C. A. Chayne, vice president in charge of Engineering Staff, in June 1956. He had been assistant chief engineer at Buick Motor since 1949, having joined Buick in 1924. His work in the fields of mechanical and electrical engineering has resulted in 26 granted patents.

- **Holle C. Luechauer** *and* **Anton F. Erickson,** *Moraine Products Division, Dayton, Ohio, for an Electroplating Fixture, No. 2,739,117, issued March 20.* This patent pertains to a plating fixture for plating engine bearings to obtain uniformity of deposit.

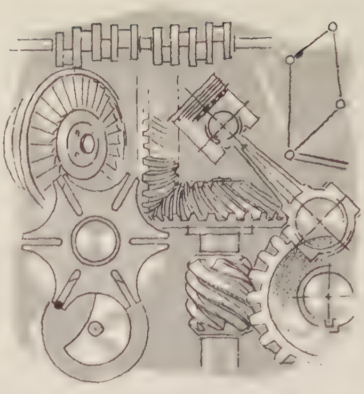
Mr. Luechauer is senior experimental chemist. His work entails supervision of the Chemical, Plating, Infrared, and Emission Spectrographic Laboratories. He received the A.B. degree from University of Cincinnati in 1927 and joined Moraine Products in 1949.

Mr. Erickson has been assistant supervisor of brake research engineering since 1954. He was employed in 1937 as brake engineer by Delco Brake Division, which joined with Moraine Products in 1942. Twelve patents have been granted as a result of his work in the field of brakes.

- **Rudolph C. Weide,** *Electro-Motive Division, LaGrange, Illinois, for an Electrical Switch Mechanism, No. 2,739,192, issued March 20.* This invention relates to a retracting means for a multiple pole switch applicable to each set of poles and individually operable to selectively render any one of the pole sets inoperable.

Mr. Weide has been a project engineer since joining Electro-Motive in 1949. His work in the design of electromechanical equipment, such as Diesel-electric oil well drilling equipment and controls, has resulted in 5 patents. He received degrees in mechanical (1922) and electrical engineering (1937) in Germany.

- **Max G. Bales,** *Delco-Remy Division, Anderson, Indiana, for Ignition Apparatus, No. 2,739,195, issued March 20.* This patent discloses a distributor-plate mounting journalled on bearings in the distributor housing for preventing plate wobble while permitting easy rotational adjustment of the plate.



Mr. Bales has been a sales engineer since 1954. After earning the B.S.E.E. from Purdue University in 1933, he joined Delco-Remy's Production Department as a student engineer. In 1939 he became a junior engineer, in 1942 a senior engineer, and, subsequently, a section engineer on ignition equipment. In 1949 he was promoted to staff engineer assigned to military equipment.

- **Orson V. Saunders,** *Frigidaire Division, Dayton, Ohio, for a 2-Temperature Refrigerator, No. 2,739,456, issued March 27.* This patent discloses a refrigerator having an insulated freezing compartment disposed above a food-storage compartment having means for conducting defrost water from around the freezing compartment down the back wall of the food-storage compartment liner to the exterior of the refrigerator cabinet through a suitable drain opening.

Mr. Saunders is supervisor of the major product line in the Household Engineering Department at Frigidaire. Employed as a senior detailer in 1936, he also has served as designer, experimental engineer, project engineer, senior project engineer, and section engineer.

- **Roy L. Bowers** *and* **Carleton J. Lauer,** *AC Spark Plug Division, Flint, Michigan, for a Drive and Control Mechanism for a Windshield Wiper, No. 2,739,681, issued March 27.* This patent relates to a mechanically driven, windshield-wiper actuating mechanism having means for parking the wiper blades at a predetermined position.

Mr. Bowers is staff engineer in the Engineering Department at AC Spark Plug, where he began his career in 1932 as a draftsman. He was granted the B.S. degree in 1930 from Michigan State University. Five previous patents cover fuel pumps and filter valves.

Mr. Lauer is now retired.

- **John Dolza** *and* **William K. Steinhagen,** *GM Engineering Staff, Detroit, Michigan, for a Thermostat, No. 2,739,835, issued March 27.* This patent pertains to a thermostat having a control actuating intermediate elements having a high thermal coefficient of expansion and corrugated to increase rigidity and turbulence of a rapidly moving gaseous medium flowing transversely over the corrugations to maintain the control member compensated for temperature.

Mr. Dolza has been engineer-in-charge of the Power Development Section at GM Engineering Staff since 1945. He joined GM at Buick Motor in 1927, transferring to Allison as consulting engineer in 1940. He attended the Polytechnico Institute, Turin, Italy, from 1920 to 1926, receiving masters degrees in electrical and mechanical engineering.

Mr. Steinhagen has been staff engineer in the Power Development Section since 1952, having joined the Engineering Staff in 1948. He was granted the B.S.E. from University of Michigan in 1947 and the M.S.E. in 1948. His work concerns refrigeration equipment and automotive engine components.

- **Argyle G. Lautzenhiser,** *Delco-Remy Division, Anderson, Indiana (now at AC Spark Plug Division), for a Snap Action Device, No. 2,740,012, issued March 27.* This patent pertains to a pressure-operated diaphragm switch wherein the opening and closing pressure required are independently adjusted to vary the range of operation to accommodate the specific use of the switch.

Mr. Lautzenhiser is a senior project engineer at AC Spark Plug, where he is responsible for product development on units of the WS-315A inertial guidance system. Previously, he was a research engineer with Delco-Remy, having joined the Division in 1940 as a laboratory technician. He earned the B.S.E.E. from Tri-State College, Angola, Indiana, in 1940.

- **Edward C. Simmons,** *Frigidaire Division, Dayton, Ohio, for a Method of Making a Heat Exchanger Element, No. 2,740,188, issued April 3.* This invention relates to a method of forming a roll-bonded evaporator having an integrally formed header chamber wherein the chamber is formed by mechanically spreading the metal walls which form the chamber.

Mr. Simmons has been a senior project engineer in the Household Engineering Department since 1955, where he is responsible for the design of defrost systems for refrigerators. After studying at University of Dayton, Brooklyn College, and University of Seattle, he joined Frigidaire in 1947. From his work on refrigeration 3 patents have resulted.

- **Carl J. Bock,** *GMC Truck and Coach Division, Pontiac, Michigan, and* **Thomas E. Dolan,** *Detroit Transmission Division, Detroit, Michigan, for a Heavy-Duty Drive Gearing and Control System, No. 2,740,303, issued April 3.* This invention relates to a multiple-unit transmission and control system having a manually operated valve associated with each unit and incorporating a common operating member for positioning the control valve of each unit.

Mr. Dolan has been an experimental engineer since 1953, having joined Detroit Transmission in 1941. He is in charge of the Experimental Department. He was granted the B.S. degree in 1947 from Iowa State College.

Mr. Bock is now retired.

- **William D. Chilton,** *Fisher Body Division, Detroit, Michigan, for a Flexible Chute, No. 2,744,601, issued May 8.* This invention pertains to a chute for dispensing small fasteners from a bin and includes a plurality of relatively axially movable, parallel, flexible plates forming a chute between their edges and surfaces.

Mr. Chilton is a senior staff assistant in the Process Development Activity of Fisher Body, having joined the Division in 1926. His work in the development of mechanical clinching tools; applicators; and hoppering, feeding, and cutoff devices has resulted in 10 patents.

- **John Dickson** *and* **Kenneth L. Hulsing,** *Detroit Diesel Engine Division, Detroit, Michigan, for a Compression-Operated Fuel Injection Pump, No. 2,740,667, issued April 3.* This patent is directed to a unit-type fuel injector pump operating in response to engine compression and includes means for timing the injection independently of engine speed.

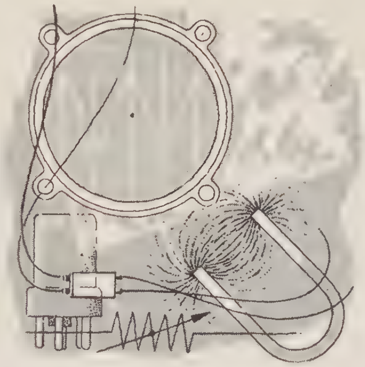
Mr. Dickson is staff engineer in charge of forward design at Detroit Diesel Engine. He has been associated with the design and manufacture of Diesel engines for 35 years, with 15 patents resulting from his work. He is a graduate of the Royal Technical College, Glasgow, Scotland.

Mr. Hulsing has been staff engineer in charge of product design since 1955, having joined Detroit Diesel Engine in 1942. He received the B.S. in chemical engineering from University of Michigan in 1936. His work on Diesel engines has resulted in 6 patents.

- **Robert L. Dega** *and* **Worth H. Percival,** *GM Research Staff, Detroit, Michigan, for Oil Purification, No. 2,741,333, issued April 10.* This invention relates to a centrifuge for removing oil impurities and includes a rotor having a dirt-separating chamber and a dirt-collecting chamber connected by a small passage.

Mr. Dega is supervisor of the Mechanical Development Department, Research Staff. He received the B.M.E. in 1948 from General Motors Institute, having worked with the Research Staff as a co-op student since 1941. He supervises developmental studies of high-temperature seals for turbines and engine air cleaners.

Mr. Percival has been a supervisor of engine development in the Mechanical Development Department, Research Staff, since 1954, where his work concerns the development of free-piston engines. He joined the Staff in 1947 as a junior engineer. Iowa State College granted him the B.S. degree in 1942, and he received the M.S. degree in 1947 from Massachusetts Institute of Technology.



- **Frank W. Brooks,** *Moraine Products Division, Dayton, Ohio, for a Brake Shoe Actuator, No. 2,741,335, issued April 10.* This patent relates to a 2-shoe, self-energizing, vehicle brake having a sliding anchorage providing automatic adjustment to maintain the shoes concentric with the brake drum.

Mr. Brooks is a project engineer in the Engineering Department of Moraine Products. In 1935 he joined GM as an inspector at Delco Products, transferring to Moraine Products in 1942. He was granted the B.S.M.E. from Case Institute of Technology in 1935.

- **Robert C. Woofter,** *Packard Electric Division, Warren, Ohio, for a Panel Lamp Socket, No. 2,741,747, issued April 10.* This patent relates to a lamp socket formed of insulating material insertable in a metal support panel, thus, separating a lamp bulb from the panel for 2-conductor electric connection, but also provided with socket chambers to receive a ground clip to ground-connect the bulb to the panel when using a single-conductor electrical circuit.

Mr. Woofter serves as a product development engineer, having joined Packard Electric in 1940. His design work has concerned ignition conduits, lamp sockets, switches, connectors, and multiple connections for automotive harnesses. He attended Fenn College, Cleveland, Ohio, and is a member of the American Society of Tool Engineers.

- **Gilbert Burrell,** *Oldsmobile Division, Lansing, Michigan, for a Valve Rotating Device, No. 2,742,029, issued April 17.* This invention pertains to a valve rotating device including a coil spring, one-way clutch cammed to an inclined, fixed pin for positively rotating an engine poppet valve.

Mr. Burrell has served as motor engineer in the Product Engineering Department since 1946. He joined Oldsmobile in 1928 as a dynamometer operator after receiving the electrical engineering degree from Michigan State University.

- **Charles W. Miller** *and* **George W. Onksen,** *Guide Lamp Division, Anderson, Indiana, for an Automatic Headlight Dimmer, No. 2,742,592, issued April 17.* This patent relates to an automatic headlight dimmer circuit similar to the Autronic-Eye and having a novel override circuit for return to high beam.

Mr. Miller is a project engineer in the Engineering Department at Guide Lamp, having joined the Division in 1928. He studied electrical engineering at Purdue University. His work concerns the development and improvement of the Autronic-Eye automatic headlamp control.

Mr. Onksen is supervisor of research for Guide Lamp. He joined GM in 1928, studied mechanical engineering at Purdue University, and joined Guide Lamp in 1930 as a General Motors Institute student. He graduated from G.M.I. in 1933 and was awarded the B.I.E. from G.M.I. in 1956. His major contributions have been in the fields of automotive headlamp lighting and automatic headlamp controls.

- **Francis H. McCormick,** *Frigidaire Division, Dayton, Ohio, for a Domestic Appliance, No. 2,742,708, issued April 24.* This patent discloses the first Frigidaire Imperial Clothes Dryer in which the heated air passes through a condenser to remove moisture from the air so that it may be discharged within a room without causing sweating of the windows.

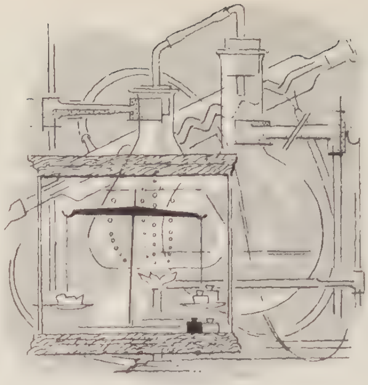
Mr. McCormick has been assistant chief engineer since 1942, having joined Frigidaire in 1936. His work on the design of ranges, washers, and other appliances has resulted in more than 40 patents. He received the B.S.E.E. from Washington State College in 1915.

- **Clarence P. McClelland,** *Fisher Body Division, Detroit, Michigan, for a Door Lock Mounting for an Instrument Panel Compartment, No. 2,744,405, issued May 8.* This invention pertains to a mounting means for securing a door lock key barrel in position in the door and is adapted to prevent tampering with the lock when the door is in its lock position.

Mr. McClelland is a senior project engineer in the Design and Drafting Engineering Department, having joined Fisher Body in 1941. He joined GM at Cadillac Motor Car in 1933. As the result of his work on windshield wipers and automotive instrument panels 3 previous patents have been granted.

- **Hans O. Schjolin,** *GMC Truck and Coach Division, Pontiac, Michigan, for a Transmission and Controls, No. 2,743,626, issued May 1.* This invention pertains to a transmission control wherein selection of neutral is achieved positively through action of hydraulic pressure applied to opposite sides of a clutch control piston.

Mr. Schjolin has been a new-development engineer in the GMC Truck and Coach Engineering Department since 1937. He was originally employed in 1923 by Yellow Truck and Coach Manufacturing Company after receiving a degree from Karlstad College, Sweden (1920) and Mitweida College, Germany (1923).



- **Samuel R. Callaway,** *GM Research Staff, Detroit, Michigan (now at Electro-Motive Division), for High-Temperature, Cobalt-Chromium Alloys, No. 2,744,010, issued May 1.* This invention relates to a high-temperature, creep-resistant, cobalt-base alloy for use as a nozzle guide vane material for gas turbines.

Mr. Callaway is chief metallurgist for Electro-Motive. He joined GM as a junior metallurgist with the Research Staff in 1940, transferring to the Manufacturing Staff in 1953. University of Minnesota awarded him the B.S. in metallurgical engineering in 1940.

- **Bertram A. Schwarz,** *Delco Radio Division, Kokomo, Indiana, for a Multi-Button Favorite-Station Tuner, No. 2,744,193, issued May 1.* This patent relates to the current, commercial form of favorite-station, signal-seeking tuned radio receiver used on General Motors cars.

Mr. Schwarz has been chief engineer since he joined Delco Radio in 1936. His developmental work in the radio industry has resulted in 28 patents in electronics, tuning systems, and loud speakers. Under his supervision are projects related to radar devices, automobile radios, and semi-conductors.

- **Alfred L. Boegehold,** *GM Research Staff, Detroit, Michigan, for a Salt Bath Furnace, No. 2,744,495, issued May 8.* This patent relates to a furnace particularly useful in the Aldip process of coating with aluminum. The furnace is adapted to contain a molten salt layer and a molten aluminum layer, a silicon carbide liner being provided in those portions contacted by the molten salt.

Mr. Boegehold was in charge of metallurgical research for 27 years. He was named assistant to the vice president in charge of Research Staff in 1952 and in 1956 was named manager of Research Staff Activities. His contributions encompass many phases of metallurgical engineering, from structural composition to metal processing techniques. He was granted a M.E. degree in 1915 from Cornell University.

- **Esten W. Spears, Jr.,** *Allison Division, Indianapolis, Indiana, for a Deicing Control, No. 2,744,992, issued May 8.* This invention controls air intake deicing heat for a gas turbine by sensing ice formation on an airflow probe in the air intake.

Mr. Spears has been a senior project engineer on turbo-jets since 1955, having joined Allison in 1946. He received the B.S.M.E. in 1942 from University of Kentucky and did post-graduate work in aeronautical engineering at California Institute of Technology. His work concerns jet engine after-burners and supersonic propulsion nozzle design.

- **William F. Holin,** *Electro-Motive Division, LaGrange, Illinois, for a Railway Vehicle Traction Motor Cooling System, No. 2,746,400, issued May 22.* This invention relates to a duct connecting the plenum chamber of a locomotive body to a traction motor housing. The duct is supported upon an intermediate member adapted to move relative to the housing and body.

Mr. Holin is a senior project engineer in the Engineering Department, having served with Electro-Motive since 1936. His work on the design and development of railroad trucks has resulted in the grant of 5 patents. His technical education was in Konstanz, Germany.

- **Louis J. Van Slooten,** *Diesel Equipment Division, Grand Rapids, Michigan, for a Hydraulic Valve Lifter, No. 2,746,437, issued May 22.* This patent pertains to a self-contained type of hydraulic valve lifter with an improved bellows for sealing against escape of hydraulic fluid.

Mr. Van Slooten is a customer contact man in the Engineering Department, having joined Diesel Equipment in 1948 as a senior detailer. In 1950 he was promoted to layout man and in 1955 to experimental engineer.

- **James O. Helvern,** *Moraine Products Division, Dayton, Ohio, for a Brake Wear Compensator, No. 2,747,694, issued May 29.* This invention relates to an automatic brake-adjusting device utilizing a ball and pin ratchet arrangement for its automatic action.

Mr. Helvern has been a senior layout man in the Engineering Department since 1940, having joined Moraine Products in 1938. He earned the B.A. degree from Wittenburg College in 1927. His work on automotive brakes has resulted in 3 patents.

- **John R. Gretzinger,** *AC Spark Plug Division, Flint, Michigan (now at Allison Division), for an Oil Filter, No. 2,747,744, issued May 29.* This patent discloses an oil filter employing a folded bellows filter element folded at each end and clamped between support plates to seal and attach the filter element to a central support tube.

Mr. Gretzinger is chief engineer, Fuel Systems and Components, at Allison. He joined GM in 1934 at AC Spark Plug, subsequently serving as chief engineer on the F-84 aircraft program at the B.O.P. Kansas City assembly plant. He was awarded the B.S.M.E. in 1934 from Purdue University.

- **Charles P. Hooverson** *and* **Mathew H. Schumer,** *Fisher Body Division, Detroit, Michigan, for a Retractable Rear Window, No. 2,747,921, issued May 29.* This patent pertains to a retractable rear window for an automobile in which the package shelf is made in telescoping sections adapted to telescope by camming action of the rear window as the window is lowered.

Mr. Hooverson has been a design leader in the Experimental Department since 1948, having joined Fisher Body in 1946. His work concerns supervision of development and progress of various design projects on body structure.

Mr. Schumer has been assistant engineer-in-charge of the Experiment and Development Department since 1947, where he supervises front and rear seat development of current and future styles. He joined Fisher Body in 1933 as a layout man on sample bodies in the wood shop.

- **Earl H. Brunke,** *Delco Appliance Division, Rochester, New York, for a Condenser Housing and Mounting, No. 2,748,185, issued May 29.* This patent pertains to a mounting bracket for a condenser attached to a split-phase motor which prevents relative movement between the bracket and the condenser.

Mr. Brunke is a junior designer with Delco Appliance, specializing in layouts, designs, and production drawings of mechanical parts and assemblies used in electric motors. He joined the Division in 1939 as a blueprint clerk.

A Typical Problem in Engineering:

Determine the Pattern Design for a Shell Molded Part from a Product Drawing

By GEORGE A. HACH
Central Foundry Division
and ROBERT M. BURTON
General Motors Institute

Solving pattern problems on design layouts reduces processing time and cost

The shell molding process has improved the quality of castings by securing surface smoothness and accuracy. The problems involved can be solved through the combined efforts of the pattern engineer and pattern layoutman. These efforts are activated by new or modified equipment and materials that contribute much to the new process. In the design of patterns, the engineer decides on the detail of the product and then considers the equipment and process desired to accomplish the final production casting. The problem presented here is to determine the points of contact between the shell mold and core, position of casting (vertical or horizontal), and the conditions desired to obtain a casting of top quality.

The shell molding process has become commonplace in foundry practice because of its many advantages in certain casting applications. This process differs from green sand molding in that a resin bonded sand is used to make the mold. As the name implies, the mold is a thin shell made by coating a heated pattern with a resin and sand mix. The mixture is baked until it acquires good mechanical strength.

A casting made by the shell mold process is desirable when a smooth surface, without machining, is needed. This smooth surface quality reduces the time spent on the machining process which, in turn, affects the cost of the part.

In the shell mold process, using the hard baked shell, draft angles of ½° and tolerances of ± 0.003 to ± 0.005 in. per in. are normal. Comparable conditions for green sand molding would be 2° draft angles and tolerances of ± 0.015 to ± 0.030 in. per in.

The pattern engineer must consider many factors when designing the pattern process equipment to produce a casting by the shell mold process. Many of the problems are the same as those encountered in green sand molding practice. One phase of pattern designing is the task of converting a product drawing for a machined part casting into a pattern layout.

The product drawing can be a representation of the final product requirements. The drawing makes reference to machined surfaces, fillets, and rounds. Where draft is required, consideration must be given to the part function and design on the drawing and pattern. The more realistic the graphical representation is, the easier it will be for the engineer to work out a pattern to satisfy specific conditions.

In many part drawings, allowance for certain inherent necessities of foundry practice have been omitted or are yet to be determined by the pattern engineer. The designer should consider, however, such factors as draft, relatively flat parting lines, and gate areas. Without these necessities the casting will lack the requirements of a practical casting.

The objective of the pattern engineer is to make the pattern and core equipment as simple, inexpensive, and serviceable as possible and to produce a functional casting at low cost.

Problem

One of the component parts of the Hydra-Matic automatic transmission is the governor valve which meters oil pressure—varying with car speed—to a shift control valve. The governor valve is housed in a grey iron governor body.

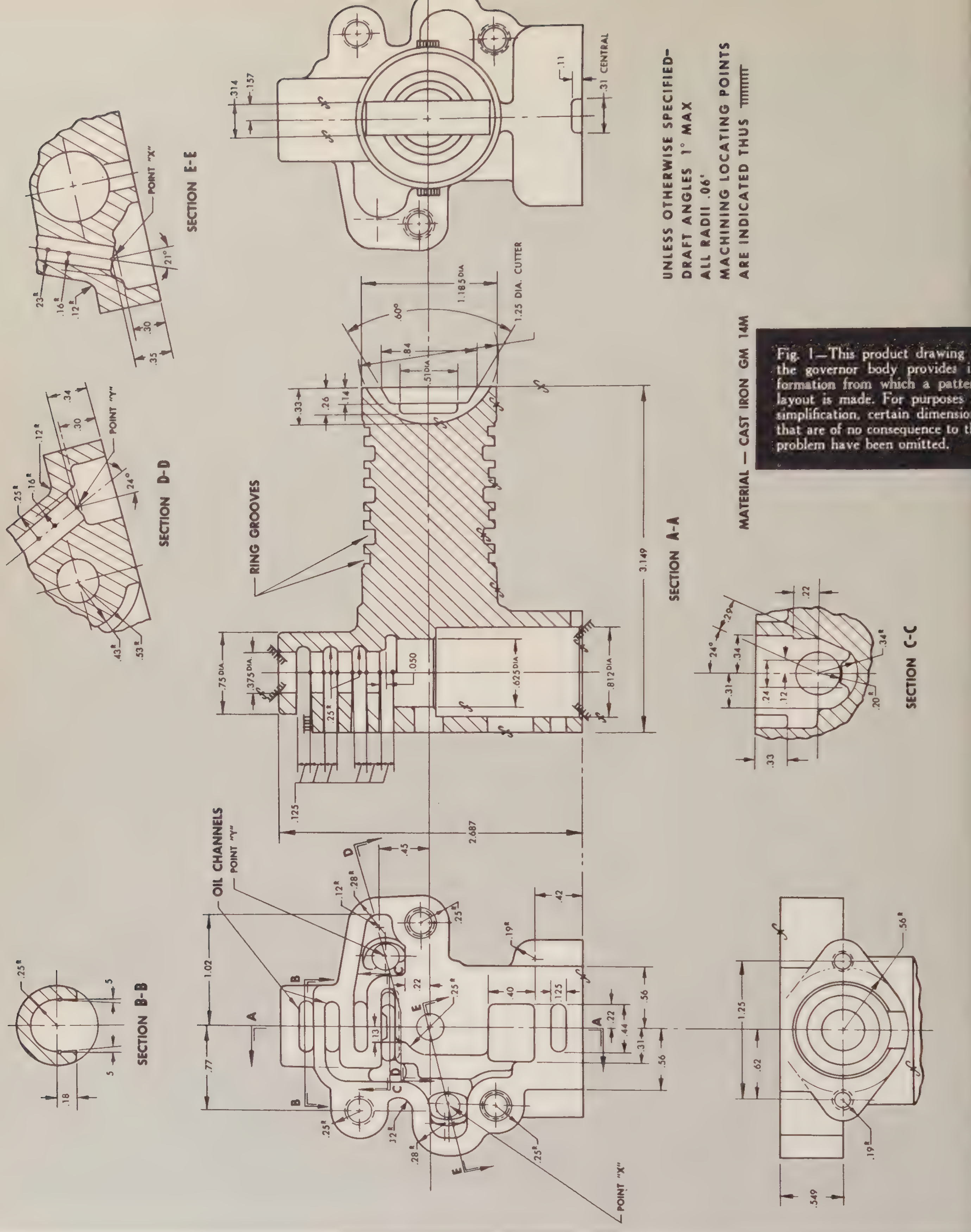


Fig. 1—This product drawing of the governor body provides information from which a pattern layout is made. For purposes of simplification, certain dimensions that are of no consequence to the problem have been omitted.

The problem is to make a pattern layout for the shell molded governor body using information obtained from the product drawing (Fig. 1). The following information is to be shown on the pattern layout:

(a) Those surfaces which will be made in the shell and those with surfaces on the core

(b) Location of the most desirable pattern and core parting lines
(c) Draft, wherever necessary
(d) Core prints with locators
(e) Designation of cope and drag
(f) Gate locations.

In addition to the above, it also is necessary to calculate the weight of the casting and the weight of the core. The casting material weighs 0.27 lb per cu in., and the core material weighs 0.06 lb per cu in.

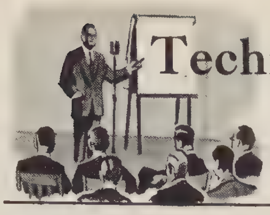
Some of the factors involved in this problem can best be considered by defining their purpose. For part (a), consideration must be given to the use of cores and the limitations of core usage. These same facts concern the use of the shell. For part (b) of the problem, consideration should be given to the fact that parting lines must be located where the core box or pattern can be separated. What influence do the parting lines have on the manufacturing process? Will they eliminate machining of draft surfaces? Do the cores have sufficient support? Are the parting lines even to facilitate an acceptable mold? These questions must be answered.

Locators for core prints are critical to maintain desirable thickness of material. A poor location of the core could result in a thin casting and possibly a complete blocking where the molten metal must flow.

The weight of a casting is important because it is a function of cost and, thus, affects the economy of foundry operation. The weight estimate varies with the design of the part. It affects material handling, as well as the schedule setup for daily furnace operation. Core weights must be determined for similar reasons.

Other considerations encountered by foundry engineers and draftsmen are the placing of gates, sprues, vents, and feeders. The gates and sprues must provide a means for directing the flow of molten metal throughout the mold cavity. The rate of flow, quantity of metal, and temperatures are important to a good casting and are influenced directly by the gates and sprues. The feeders provide a reservoir of metal for shrinkage as the metal cools. The vents allow the gases which are formed to escape, thus decreasing the possibility of a mold "blowing out," or exploding.

The solution to the problem will be presented in the April-May-June 1957 issue of the General Motors Engineering Journal.



Technical Presentations by GM Engineers

Speaking appearances by General Motors engineers are one of the ways in which GM makes available to the public information on current engineering developments. Listed below are some of the recent speaking engagements by GM personnel before civic organizations, in college classrooms, and as panel members at technical society meetings. Educators who wish assistance in obtaining the services of GM engineers to speak before engineering classes or other student groups may write to Educational Relations Section, Public Relations Staff, General Motors Technical Center, P.O. Box 177, North End Station, Detroit 2, Michigan.

GM personnel who have made recent presentations are as follows:

Aeronautical Engineering

Earl W. Pierce, senior engineer, Spark Plug Engineering Department, AC Spark Plug Division, before aircraft distributors and customers, Standard Aero Ltd., Toronto, Canada, September 24, and Montreal, Canada, September 27; title: Aircraft Spark Plug Engineering and Design.

Robert A. Rogers, supervisor, Aerodynamics Department, Aeroproducts Operations, Allison Division, before the Society of Automotive Engineers national aeronautic meeting, Los Angeles, California, October 4; title: Propellers for High-Speed Aircraft.

Automotive Engineering

Carleton J. Lauer, staff engineer, Automotive Products Department, AC Spark Plug Division (now retired), before the Kiwanis Club, Lake Fenton, Michigan, June 27; title: Why an Oil Filter?

Howard K. Gandelot, engineer-in-charge, Vehicle Safety Section, GM Engineering Staff, before a joint meeting of the Grosse Pointe and Detroit Traffic Safety Associations, Grosse Pointe, Michigan, July 25; title: A History of Automotive Safety Research; and before the National Lubricating Grease Institute, Chicago, Illinois, October 22; title: Techniques for Vehicle Safety Testing.

Harry C. Doane, assistant to the vice president, GM Engineering Staff, before the American Association of Motor Vehicle Administrators sub-committee, Detroit, Michigan, July 27; title: The 4-Lamp Headlighting System—History and Appraisal; and before the 1956 annual conference of the American Association of Motor Vehicle Administrators, Winnipeg, Canada, August 28; title: The New 4-Lamp Headlighting System for Motor Vehicles.

Blair Thompson and **Henry Smith**, senior project engineers, Hydraulic Group, Saginaw Steering Gear Division, before the summer conference on automotive front end service, Ferris Institute, Big Rapids, Michigan, August 2 and August 16, respectively; title: Development and Service of Saginaw Power Steering.

George L. Rothrock, staff engineer, Axle and Transmissions Department, Cadillac Motor Car Division, before the S.A.E. national tractor meeting, Milwaukee, Wisconsin, September 12; title: Dynamometer Testing of Gears in a Normal Environment.

Frank J. Condon, staff engineer, Product Engineering Department, Detroit Transmission Division, before the foremen's meeting, Acadia Synthetic Products Division of Western Felt Works, Chicago, Illinois, September 29; title: Quality Requirements of Transmission Seals.

William E. Sehn, assistant engineer-in-charge, Design and Drafting Department, Fisher Body Division, before the American Society of Body Engineers, Detroit, Michigan, October 17; title: How Can We Seal 4-Door Hardtops?

Electrical Engineering

Robert W. Chase, project engineer, Project Engineering Department—Electronics, AC Spark Plug Division, before the S.A.E. student chapter, General

Motors Institute, Flint, Michigan, August 1; title: An Introduction to Army's 75 mm Skysweeper Gun and Its T-38 Fire Control System; and before the fall conference for physical science teachers, Michigan Junior College Association, Flint, Michigan, September 19; title: New Approaches in Teaching Science Courses.

Robert J. Johnston, Jr., engineer, Electronic Development Department, AC Spark Plug Division, before the Kiwanis Club, Lake Fenton, Michigan, August 29; title: Three-Dimensional Images.

R. V. Fisher, supervisor, and **A. F. Welch,** assistant head, Instrument Section, Technical Facilities and Services, GM Research Staff, before the 11th annual conference of the Instrument Society of America, New York, New York, September 18; title: Flexible Temperature Controllers and Plug-In Connectors.

B.H. Hefner, electrical engineer, Engineering Department, Electro-Motive Division, before the American Institute of Electrical Engineers, Petroleum Industry Division, Kansas City, Missouri, September 18; title: Application of Direct Current Machines to Oil Well Drilling; and before the American Society of Mechanical Engineers, Petroleum Division, Dallas, Texas, September 25; title: Application of Diesel-Electric Traction Power to Oil Well Drilling.

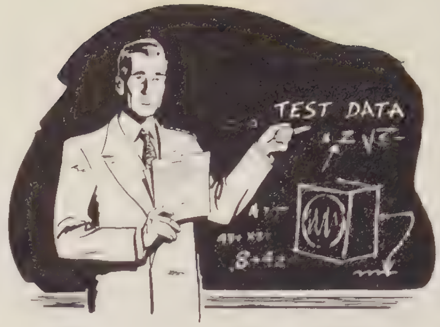
Paul C. Skeels, head, Experimental Engineering Department, GM Proving Ground, before the 11th annual conference of the Instrument Society of America, New York, New York, September 20; title: Automotive Proving Ground Instrumentation.

I. M. Levy, consulting engineer, Engineering Department, Delco Products Division, before the American Institute of Electrical Engineers rotating machinery meeting, Chicago, Illinois, October 4; chairman of the meeting.

Ralph H. Bertsche, electrical engineer, Engineering Department, GMC Truck and Coach Division, before the S.A.E. national transportation meeting, New York, New York, October 10; title: Trends in Motor Coach Electrical Systems.

General Engineering

Monta E. Hale, project engineer, Engineering Calculations Department, Allison Division, before the "650" Scientific Computation Seminar, Endicott, New York, June 20; title: The Allison EASE II System for the IBM 650 Computer.



Leonard E. A. Batz, project engineer, Special Design Standards Department, AC Spark Plug Division, before the Optimist Club, Flint, Michigan, July 17; title: Engineering Law and Ethics; and before the Lions Club, Genesee, Michigan, August 16; title: Engineering, A Dynamic Profession.

Leo Marcus, project engineer, Engineering Calculations Department, Allison Division, before the Association for Computing Machinery, Los Angeles, California, August 27; title: An Algorithm to the Method of Curve Fitting by the Process of Least Squares.

Helen Barlett, supervisor of ceramic research, Research Department, AC Spark Plug Division, before the Shakespeare's Club, Flint, Michigan, September 10; title: Gems.

R. W. Leland, staff engineer, Engineering Department, Delco Products Division, before a group of students and graduate trainees, Dayton, Ohio, September 11; title: The Challenge of Engineering.

A. S. McClimon, manager, Sales Development Department, Euclid Division, before the S.A.E. national tractor meeting, Milwaukee, Wisconsin, September 11; title: Tubeless Tires on Earthmoving Equipment.

William K. Steinhagen, staff engineer, Power Development Section, GM Engineering Staff, before the Chicago Section of the American Society of Refrigeration Engineers, Chicago, Illinois, September 13; title: Design of an Axial-Type Refrigeration Compressor.

John Campbell, technical director, GM Research Staff, before the North American Gasoline Tax Conference, Mackinac Island, Michigan, September 14; title: Partners in Transportation Progress—We Are in the World's Largest Power Business.

Claude W. Willis, safety director, Plant Safety Department, Delco Products Division, before the traffic safety and traffic controls committees, judges of traffic courts, chiefs of enforcement agencies, representatives of the coroner's office, and legislative groups, Dayton, Ohio, September 20; chairman of meeting on traffic safety and controls.

Dale A. Winnie, patent attorney, Patent Section, GM Central Office, before the Michigan Patent Law Association, Detroit, Michigan, October 2; title: Ethics for Patent Attorneys.

Mauri Rose, special engine and vehicle development engineer, Product Information Department, Chevrolet Motor Division, before the Southeastern Michigan Association of Chiefs of Police, Grosse Pointe, Michigan, October 4; title: Safe High-Speed Driving.

Darl F. Caris, head, Automotive Engines Department, GM Research Staff, before the Detroit Section of the S.A.E., Detroit, Michigan, October 8; title: Are Pistons Here to Stay?

Jean L. Carpenter, patent attorney, Patent Section, GM Central Office, before the engineers of the Harnischfeger Corporation, Milwaukee, Wisconsin, October 9; title: Things Every Engineer Should Know about Patents.

Donald L. Boyes, general manager, Hyatt Bearings Division, before the executive development conference of the Newark College of Engineering, Newark, New Jersey, October 17; title: Executive Policies and Methods.

Martin J. Caserio, chief engineer, automotive products and research, Engineering Department, AC Spark Plug Division, before the National Association of Cost Accountants, Frankenmuth, Michigan, October 17; title: Creativity—How Does It Affect You.

Louis J. Pedicini, senior project engineer, Foundry Department, Process Development Staff, before the Detroit Chapter of the American Foundrymens Society, Detroit, Michigan, October 18; title: Shell Cores.

John H. Smith, section head, Hydrostarter Engineering Department, Aeroproducts Operations, Allison Division, before the National Conference on Industrial Hydraulics, Chicago, Illinois, October 19; title: Development of a Hydraulic Starter for Cranking Diesel Engines.

K. E. Spires and **J. M. Rodgers,** project engineers, Engineering Department, Delco Products Division, before the Dayton area high school juniors, Dayton, Ohio, October 22; title: Our Wives' Fur Coats—and Engineering.

Industrial Engineering

Edward R. Clark, supervisor of quality control, and **Stanley A. Brown,** quality control engineer, Inspection Department, Detroit Transmission Division, before the American Society for Quality Control, University of Michigan, Ann Arbor, Michigan, September 8; chairman of forum and moderator of educator session of forum on acceptance sampling, respectively.

W. W. Perkins, manager of electronics instrumentation, Product Engineering Department, New Departure Division, before the Rotary Club, Bristol, Connecticut, September 11; title: Components of Automation.

Robert W. Metzger, instructor, Industrial Engineering Department, General Motors Institute, before the 8th annual industrial engineering conference, Michigan State University, East Lansing, Michigan, September 10 through 14; seminar leader in Linear Programming.

Arthur B. Wright, industrial engineer, Work Standards and Methods Engineering Section, Process Development Staff, before the 8th annual industrial engineering conference, Michigan State University, East Lansing, Michigan, September 14; title: What's New in Methods Engineering in General Motors.

Manufacturing

Carl Schaefer, supervisor of ceramic development and control, Research Department, AC Spark Plug Division, before an engineering class, Massachusetts Institute of Technology, Cambridge, Massachusetts, July 18; title: Controls Required and Problems Encountered in Hydrostatic Pressing.

Howard L. Roat, manufacturing manager, AC Spark Plug Division, before the machine tool sales conference, Purdue University, West Lafayette, Indiana, July 31; title: The User Looks at the Machine Tool Industry.

Clyde L. Fanning, assistant chairman, Machine and Wood Shops, General Motors Institute, before the Cleveland Chapter of the American Society of Tool Engineers, Cleveland, Ohio, October 23; title: Carbide Tool Training in General Motors.

Metallurgy and Bearing Materials

Charles E. Norton, chief metallurgist, Product Engineering Department, New Departure Division, before the Pennsylvania Chapter of the American Society for Metals, University Park, Pennsylvania, September 7; title: Use of Vacuum-Melted Materials in Ball Bearings.

Carl J. Leistner, experimental spectrographic chemist, Metallurgical Department, Allison Division, before the Ohio Valley Section of the Optical Society of America, Dayton, Ohio, September 18; title: Metal Transfer Techniques used in Spectroanalysis.

A. J. Gentile, metallurgical product engineer, **Charles R. Gillette,** chief chemist, and **Leland D. Cobb,** manager of research and development, Product Engineering Department, New Departure Division, before employes of the Wright Aeronautical Division, Woodbridge, New Jersey, September 26; titles: Ball Bearing Materials for High Temperature Operation, Lubrication of High Speed and High Temperature Ball Bearings, and New Departure Aircraft Engine Bearing Test Program, respectively.

Heinz Hanau, supervisor of aircraft application section, Product Engineering Department, New Departure Division, before employes of the Wright Aeronautical Division, Woodridge, New Jersey, September 26; title: Ball Bearings for Aircraft Gas Turbines; and before the National Lubricating Grease Institute and Coordinating Research Council, Chicago, Illinois, October 22; title: Problems Associated with Grease Lubrication of High-Speed, High-Temperature Bearings.

J. M. Sullivan, agricultural project engineer, and **P. F. Reed,** supervisor of bearing service engineering, Engineering Department, New Departure Division, before the Worthing Mower Company ball bearing seminar, Stroudsburg, Pennsylvania, October 11; title: New Bearing Developments and participation in question-and-answer session, respectively.

Research

J. D. Thomas, senior research chemist, Electro-Chemistry Department, and **Gene Leithauser,** supervisor of paint research, Chemistry Department, GM Research Staff, before the American Electroplaters Society, Washington, D. C., June 17 and June 20; title: Leveling—Definition, Measurement, and Understanding and Enameling of Chromium Plate, respectively.

R. L. Scott, junior chemist, Physics and Instrumentation Department, GM Research Staff, before the American Society for Testing Materials, Atlantic City, New Jersey, June 19; title: Chemical Polishing of Steel for Electron Metallography.

N. W. Schubring, research engineer, Physics and Instrumentation Department, GM Research Staff, before the Michigan Chapter of the American Welding Society, Detroit, Michigan, May 9; title: ABC's of Ultrasonic Testing.

Max McKenzie, safety supervisor, Personnel Department, GM Research Staff, before the State Fire Chief's Conference, Grand Rapids, Michigan, August 3; title: Fire Fighting Problems Involved with Radioactive Materials.

Gregory Flynn, assistant head, Mechanical Development Department, GM Research Staff, before the S.A.E. national west coast meeting, San Francisco, California, August 8; title: Observations on 25,000 Hours of Free Piston Engine Operation.

William G. Agnew, senior combustion engineer, and **Wayne Daniel,** senior research physicist, Fuels and Lubricants Department, GM Research Staff, before the 6th combustion symposium, Yale University, New Haven, Connecticut, August 24; title: Comparison of Engine and Flat-Flame Burner Cool Flame Emission Spectra (with J. T. Agnew and K. Wark, Jr.) and Flame Quenching at the Walls on an Internal Combustion Engine, respectively.

Leonard G. Johnson, senior research mathematician, Special Problems Department, GM Research Staff, before the 116th annual meeting of the American Statistical Association, Detroit, Michigan, September 8; title: Some Problems in Life Testing.

Raymond L. Mattson, assistant head, Engineering Mechanics Department, GM Research Staff, before the Institute of

Mechanical Engineers, London, England, September 13; title: Fatigue, Residual Stresses, and Surface Cold Working.

C. F. Nixon, head, and **H. A. Kahler,** liaison engineer, Electro-Chemistry Department, GM Research Staff, before the American Electroplaters Society, Philadelphia, Pennsylvania, September 24; title: Comments on the Use of Anodized Aluminum for Automobile Trim Parts.

E. F. Weller, assistant head, **N. W. Schubring,** research engineer, and **M. E. Fitch,** research engineer, Physics and Instrumentation Department, GM Research Staff, before the National Electronics Conference, Chicago, Illinois, October 1; title: A Peak Pressure Distribution Counter for Engine Fuel Studies.

Joseph B. Bidwell, head, **Raymond L. Mattson,** assistant head, **W. S. Coleman,** supervisor, **Milton Simpson,** research engineer, and **J. G. Roberts,** research engineer, Engineering Mechanics Department, GM Research Staff, and **G. H. Robinson,** supervisor, and **R. F. Thomson,** head, Metallurgy Department, GM Research Staff, before the American Society of Metals national metal congress, Cleveland, Ohio, October 11; title: Factors Affecting the Fatigue Durability of Carburized Steel.

1956 General Motors Conference for Engineering Educators

The 5th annual GM Conference for Engineering Educators was held in Detroit, Michigan, July 15 through July 31 under the direction of **Kenneth A. Meade,** director, Educational Relations Section, GM Public Relations Staff. Co-hosts and chairmen of the Conference, designed to orient engineering educators on the product and production activities of General Motors, were **Charles A. Chayne,** vice president in charge of Engineering Staff, and **John J. Cronin,** vice president in charge of Manufacturing Staff.

Twenty-six engineering educator guests attended as representatives of colleges and universities in Canada and nearly all areas of the United States. After introductory sessions at the GM Technical Center, Warren, Michigan, the educators spent July 24 through July 27 on field assignments at General Motors Divisions, where they conferred with management on Divisional operations. Re-convening in Detroit, the educators presented their views and observations to their Conference hosts.

Participants in the Conference for Engineering Educators included the following GM personnel:

Louis C. Goad, executive vice president, General Motors; **Charles A. Chayne,** vice president in charge of Engineering Staff; **John J. Cronin,** vice president in charge of Manufacturing Staff; **Robert M. Critchfield,** vice president in charge of Process Development Staff; **George A. Jacoby,** director of personnel relations, GM Central Office; **Edwin L. Yates,** salaried personnel activity, GM Central Office; and **William F. Andersen,** director, Budget and Procedure Section, GM Central Office; before the introductory general session, GM Technical Center, July 16; speakers.

Dr. Lawrence R. Hafstad, vice president in charge of Research Staff, host for the Research Staff program, GM Technical Center, July 17. **John M. Campbell,** technical director of Research Staff; **Arthur F. Underwood,** head, Mechanical Development Department; **William A. Turunen,** head, Gas Turbines Department; and **Joseph B. Bidwell,** head, Engineering Mechanics Department, GM Research Staff; speakers.

Charles A. Chayne, vice president in charge of Engineering Staff, host for the Engineering Staff program, GM Technical Center, July 18. **Lyle A. Walsh,** manager of Engineering Staff Activities; **Maurice A. Thorne,** engineer-in-charge, Vehicle Development Section; **Gerhard C. R. Kuiper,** engineer-in-charge, Passenger Car Development Section; **Roland V. Hutchinson,** assistant engineer-in-charge, Auto Ordnance Section; **Oliver K. Kelley,** engineer-in-charge, Transmission Development Section; **John Dolza,** engineer-in-charge, Power Development Section; and **Von D. Polhemus,** engineer-in-charge, Structure and Suspension Development Section, GM Engineering Staff; speakers.

Robert M. Critchfield, vice president in charge of Process Development Staff, host for the Process Development Staff program, GM Technical Center, July 19. **Rodger J. Emmert,** assistant to the vice president; **Glen R. Fitzgerald,** director, Process Development Section; **Robert D. McLandress,** director, Work Standards and Methods Engineering Section; **Rolly L. Wilhite,** director, Production Engineering Section; **John Q. Holmes,** supervisor of equipment and operations; and **David Milne,** supervisor of materials and processes, Production Engineering Section, GM Process Development Staff; speakers.

Harley J. Earl, vice president in charge of Styling Staff, host for the Styling Staff program, GM Technical Center, July 20. **William L. Mitchell,** director of Styling Staff; **G. T. Christiansen,** executive assistant to the vice president—administration; **Robert J. Lauer,** executive assistant; **Robert F. McLean,** chief designer, Research Studio; and **Charles A. Jordan,** chief designer, Special Studio No. 3, GM Styling Staff; speakers.

H. H. Barnes, director, GM Proving Ground, host for the GM Proving Ground program, Milford, Michigan, July 21. **L. C. Lundstrom,** assistant director of GM Proving Ground; **Kenneth A. Stonex,** head, Technical Data Department; and **J. W. Podesta** supervisor of education and training, GM Proving Ground; tour leaders.

Guy R. Cowing, president, General Motors Institute, host for the General Motors Institute program, Flint, Michigan, July 23. **John F. Gordon,** vice president and group executive, General Motors, and chairman of Board of Regents, General Motors Institute; **Harold M. Dent,** administrative chairman, Cooperative Engineering Program; **William H. Lichty,** in charge of chassis design, Mechanical Engineering Department; **Edward A. Reed,** assistant chairman, Industrial Engineering Department; and **Robert F. Tuttle,** acting chairman, English-Cultural Studies Department, General Motors Institute; speakers.

Donald H. Loughridge, special executive assistant, GM Research Staff, spoke before a joint session of the educators and GM executives at a dinner meeting at the GM Technical Center, July 30.

The educators met for the closing general session of the Conference at the GM Technical Center on July 31 to sum up and present their observations to their hosts. **Anthony G. De Lorenzo,** director of GM Public Relations Staff, addressed the educators in the afternoon. Dr. G. G. Brown, dean, College of Engineering, University of Michigan, presented "Current Problems in Engineering Education" followed by a discussion period and the Conference adjournment.

Solution to the Previous Problem:

Determine the Diameter and Length of a Pin for a Pin-Bushing Type Joint by Bending Stress Evaluation

By BENJAMIN A. SLUPEK
and FRED L. MAIN
Euclid Division

Assisted by William A. Fugenschuh
General Motors Institute

Simultaneous solution of bending and bearing stress equations determine optimum pin dimensions

The design of pin-bushing type joints can impose operational problems where heavy reversing loads produce a wear pattern which is characteristic of extreme pin deflection. Designing the pin to bending stress limitations in addition to bearing stress serves to control this deflection problem. Expressing the relation between pin diameter and pin length in the basic stress formulae and simultaneously solving the resulting equations give the optimum pin dimensions. This is the solution to the problem presented in the October-November-December 1956 issue of the GENERAL MOTORS ENGINEERING JOURNAL. The diameter and length of the pin required to withstand the applied load are 2⅛ in. and 5¾ in., respectively.

THE first step in the solution to the problem is concerned with calculating the applied load P concentrated at the mid-point of the pin's length (Fig. 1). This load is calculated by multiplying the effective steering-jack piston area by the maximum hydraulic pressure applied to the pin. The effective piston diameter of the steering jack was given as 5.50 in. This is equal to an effective piston area A of

$$A = \frac{\pi}{4}(5.50)^2 = 23.80 \text{ sq in.}$$

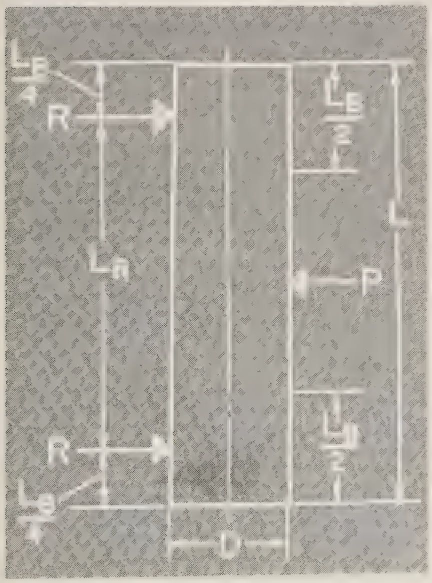


Fig. 1—To calculate the required diameter D and length L of the pin subjected to an applied load P concentrated at the center of the pin, it is first necessary to express the bearing length L_B and the distance L_R between the reactions R in terms of pin length L.

The maximum hydraulic pressure applied by the steering jack to the pin was given as 1,000 psi. The applied load P, therefore, is equal to

$$P = 1{,}000\ (23.80) = 23{,}800 \text{ lb.}$$

Since the bearing stress and the bending stress are dependent on both the diameter of the pin and the pin length, the formulae for the stresses must be reduced to equations in terms of these dimensions. A simultaneous solution of the resulting equations can then be made. A graphical rather than an analytical solution is preferred because it provides

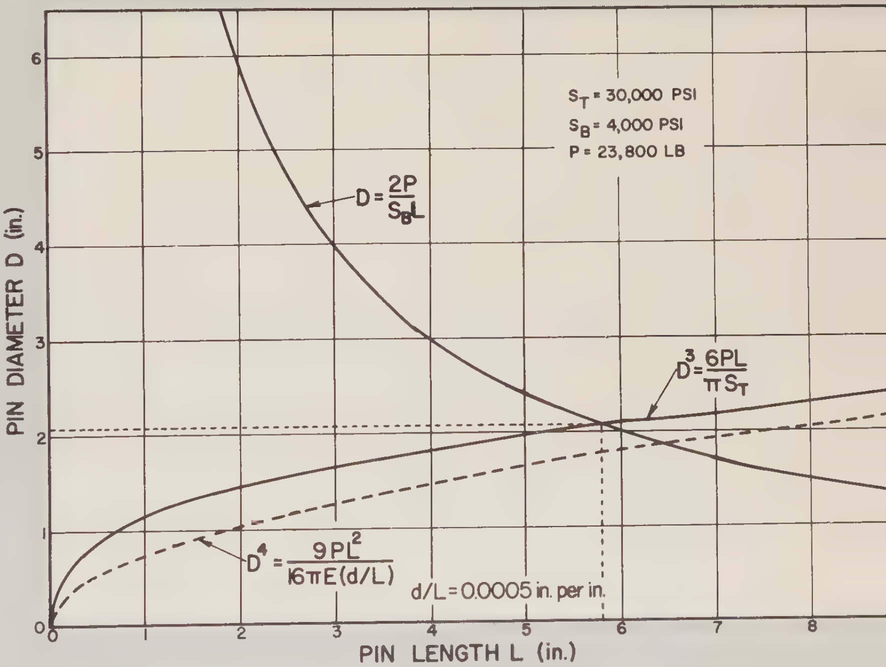


Fig. 2—The simultaneous solution of the 2 basic equations $D = 2P/LS_B$ and $D^3 = 6PL/\pi S_T$ by graphical means establishes the required diameter D and length L of the pin necessary to withstand the applied load P. The required diameter (2⅛ in.) and length (5¾ in.) are established at the intersection of the 2 curves. The dashed curve based on unit deflection d of the pin, where the unit deflection d/L was held to 0.0005 in., indicates how the diameter variation with length based on bending stress closely approximates the variation based on unit deflection.

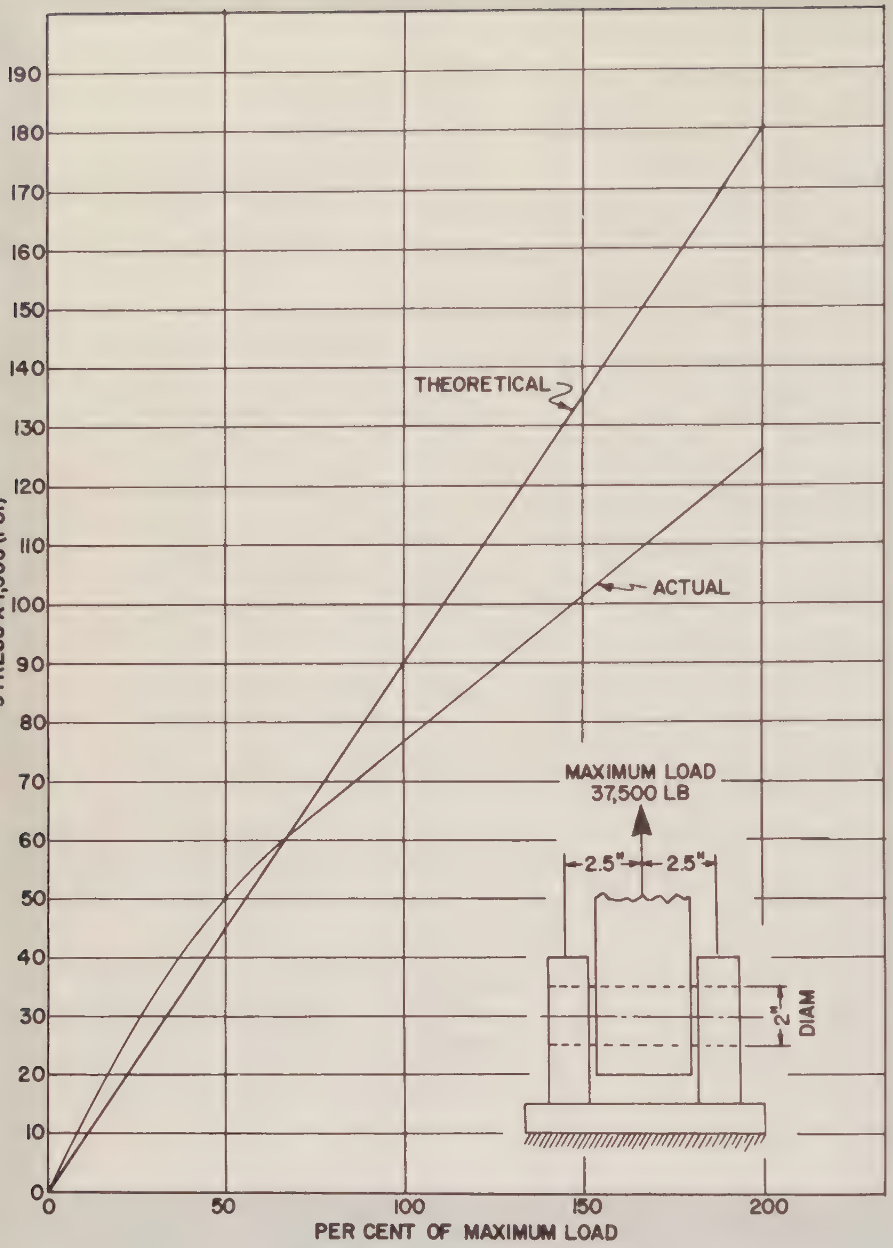


Fig. 3—A test performed on a 2-in. diameter steel pin, to check the extent of error which might be introduced by the concentrated load method of analysis, consisted of placing a strain gauge at the maximum point of stress located at the pin's center. The test results indicated that for extremely high loads excessive deflection of the pin caused the resultant bearing reaction to move in, and considerable difference between actual bending stress, as indicated by the strain gauge, and calculated bending stress was introduced.

an overall picture of the effect of pin dimension changes.

The initial approach is to express the bearing length L_B, which is the sum of the lengths of the pin within the supporting "ears," and the distance L_R (Fig. 1) between reactions in terms of the total pin length L. In order that the bearing stress be equal along the entire pin, the total bearing reaction force should be distributed along ½ of the pin length or

$$L_B = L/2.$$

Similarly, the distance between bearing reactions L_R can be expressed as

$$L_R = 3L/4.$$

The formulae for bearing stress S_B and bending stress S_T are as follows:

$$S_B = P/DL_B$$
$$S_T = 8PL_R/\pi D^3$$

where

S_B = bearing stress (psi)
P = pin load (lb)
D = pin diameter (in.)
L_B = total bearing length (in.)
S_T = bending stress (psi)
L_R = distance between bearing reactions (in.).

Substituting the value for L_B and L_R into the above equations for bearing stress and bending stress and rearranging terms gives the following basic equations for pin diameter:

$$D = 2P/LS_B$$
$$D^3 = 6PL/\pi S_T.$$

If the calculated value of 23,800 lb for the pin load P and the given values of 4,000 psi for the bearing stress and 30,000 psi for the bending stress are substituted into the above equations for pin diameter, 2 curves can be plotted (Fig. 2) where the pin diameter D is a function of pin length L. The intersection of these 2 curves indicates the optimum value for the diameter and length of the pin. For this problem, the length selected would be 5¾ in., and the pin diameter would be 2⅛ in.

The unit deflection d of the pin can be expressed as follows:

$$d = 4P(L_R)^3/3\pi ED^4$$

where

E = modulus of elasticity of the steel pin (30,000,000 psi).

Substituting into this equation the value of L_R in terms of pin length L will give the following equation for deflection in terms of pin length:

$$d = 9PL^3/16\pi ED^4.$$

Rearrangement of the terms in the above equation gives the following expression for pin diameter:

$$D^4 = 9PL^2/16\pi E\ (d/L)$$

where

d/L = deflection per in. of pin length (the d/L term is a constant in the equation for pin diameter and would be determined by the designer for a particular application).

If a curve based on unit deflection d of the pin is drawn on the same graph (Fig. 2) used to determine the diameter and length of the pin, where the value of d/L is held to a desired value (in this case $d/L = 0.0005$ in. per in.), it will be seen how the diameter variation with length based on bending stress closely approximates the variation based on unit deflection.

Summary

As a check on the extent of error which might be introduced by using the concentrated load method of analysis, a test was made on a 2-in. diameter steel pin whereby a strain gauge was placed at the maximum stress point at the center of the pin. Curves were drawn showing bending stress plotted against per cent of maximum load (Fig. 3). The results indicated that for extremely high loads excessive deflection caused the resultant bearing reaction to move in and considerable difference between actual and calculated bending stress results was introduced. However, poor bearing qualities also would be present in this range and in most cases subsequent failure of the pin due to bending fatigue would result.

Back Copies of the JOURNAL Available

Extra copies of certain back issues in Volumes 2 and 3 of the General Motors Engineering Journal are available to readers upon request. Copies may be obtained of the following issues:

January-February 1955,
Vol. 2, No. 1
March-April 1955,
Vol. 2, No. 2
July-August 1955,
Vol. 2, No. 4
November-December 1955,
Vol. 2, No. 6
January-February 1956,
Vol. 3, No. 1
March-April 1956,
Vol. 3, No. 2
May-June 1956,
Vol. 3, No. 3.

Requests may be directed to the Educational Relations Section, Public Relations Staff, GM Technical Center, P.O. Box 177, North End Station, Detroit 2, Michigan.

Contributors to Jan.-Feb.-Mar. 1957 Issue of GENERAL MOTORS ENGINEERING JOURNAL

WILLIAM J. ADAMS,

co-contributor of "Evolution of a Twin Engine, 4-Wheel Drive, Earthmoving Carry-Scraper," was a senior development engineer and consultant at Euclid Division prior to his retirement in October 1956. In this position he directed the developmental program for Euclid's first twin engine, 4-wheel drive carry-scraper and the present TS-18 overhung engine scraper.

At the time of his retirement Mr. Adams had over 50 years' experience in the earthmoving industry—30 of them in designing and building carry-scrapers. In the mid 1920s he developed and perfected the load-carrying front apron, which served to double the capacity of scrapers then in use and also allowed the scraper load to be transported on wheels. In 1927 he formed his own company for the manufacture of the first western type of carry-scraper. In 1933 he redesigned this scraper to include a hydraulic method to power and control scraper action during loading and unloading operations. This scraper, called the Continental Carry-Scraper, was manufactured and sold from 1934 to 1939 by the Allis-Chalmers Company. In 1939 Mr. Adams sold his scraper patents and designs to Gar-Wood Industries of Detroit, where he managed the development of 2-wheel and 4-wheel carry-scrapers. From 1940 to 1946 he did consulting work for the R. G. LeTorneau Company on U. S. Army Corps of Engineers projects. During this period he also worked with the Bucyrus-Erie Company, where he did basic developmental work on a 4-wheel drive carry-scraper.

Mr. Adams joined Euclid in 1947 to direct the development of the 4-wheel drive carry-scraper, of which he writes. He has authored numerous papers on scraper design and the applications of the carry-scraper to various earthmoving projects. Patents granted as the result of his work cover many phases of scraper design and development.

DAVID C. APPS,

contributor of "Applying Physics in Industry: How Studies of Vibration and Noise Aid Developmental Work," is head of the Noise and Vibration Laboratory of General Motors Proving Ground, Milford, Michigan.

The Proving Ground Section is an activity of the GM Engineering Staff to provide facilities for testing GM cars and trucks and their accessories and for comparing them with competitive makes. In addition to 3,874 acres at Milford, the Proving Ground maintains a 2,280-acre Desert Proving Ground at Mesa, Arizona, for hot weather testing and the Pike's Peak engineering test headquarters at Manitou Springs, Colorado, for testing under extreme grade and altitude conditions.

Mr. Apps joined the Proving Ground in 1934 as a test driver. He became an acoustical technician in the Noise and Vibration Laboratory in 1936, was promoted to assistant department head in 1939, and assumed his position as head of the Laboratory in 1945. His work concerns industry-wide activities directed toward vehicle noise control.

The University of Michigan granted Mr. Apps the B.S.E.E. degree in 1934. His technical society membership includes the Acoustical Society of America and the Society of Automotive Engineers, in which he is chairman of the Truck Noise Subcommittee of the Truck and Bus Technical Committee. He also is a member of the sectional committee on acoustics, vibration, and shock of the American Standards Association and a member of the editorial board of *Noise Control* magazine.

Mr. Apps is the author of several published papers in the field of noise control, including "The Use of Binaural Tape Recording in Automotive Noise Problems," *Journal of the Acoustical Society of America* (1952); "Quieter Automotive Vehicles," *Noise Control* (1955); "Tire Thump: Its Mechanism and Measurement," *S.A.E. Transactions* (1955); and "The A.M.A. New-Vehicle Noise Specification," *Noise Control* (1956).

WILLIAM BLINDER,

contributor of "Special Materials for Unusual Ball Bearing Applications," has been a senior research and development engineer with New Departure Division since 1954, having joined the Division as a research and development engineer in 1951.

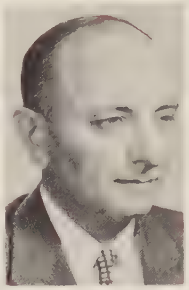
Currently Mr. Blinder is in charge of a comprehensive program to develop ball bearings for high-speed, high-temperature, heavily loaded jet engine applications. This involves research on new and unusual materials, regarding their properties of strength, hot hardness, fatigue, and compatibility, and includes studies of the effect of material design and lubrication variables on bearing performance. In connection with this program several unusual pieces of test equipment have been designed, including a fully instrumented, full-scale test rig to allow the study of bearing performance under conditions simulating jet engine operation.

Mr. Blinder's previous work was concerned with studies of friction and galling characteristics of possible ball bearing materials and effects of improved processing methods on bearing life. One project involved the successful determination of the effect of magnetism on bearing performance and the development of means for demagnetizing ball bearings.

In 1947 Mr. Blinder was granted the B.S.M.E. from the University of Connecticut, where he was a member of Alpha Tau Phi, honorary engineering society. From 1947 to 1951 he was a development engineer with Knolls Atomic Power Laboratory.

Mr. Blinder is an associate member of the American Society of Mechanical Engineers; he is a member of the Society's Hartford Section executive board and chairman of its membership committee.

ALBERT DeFEZZY,



co-contributor of "How a Cutaway Exhibit Was Built to Show the Operation of a 2-Cycle Diesel Engine," is director of drafting at Detroit Diesel Engine Division, where his work consists of co-ordinating design of the basic engine and application sections.

Mr. DeFezzy joined General Motors in 1937 as a member of the Research Laboratories Division (now the GM Research Staff), where he was concerned with the design of Diesel engine components in the capacity of layout draftsman.

When Detroit Diesel Engine Division was organized in 1937 for the production of small Diesel engines, Mr. DeFezzy was transferred from Research Laboratories to Detroit Diesel Engine and was promoted to design engineer. During World War II, he was responsible for working out design problems in connection with war-time applications of Diesel power plants. His work with Detroit Diesel Engine also has included responsibility for finalizing for production the design of the Model 6-110 engine, the largest Diesel engine (300 hp, 6-cylinder, 660 cu in. displacement) built by the Division. He was associated with the design and development of horizontally-mounted Diesel power plants, such as used for railway air conditioning and first applied on the "Train of Tomorrow," the General Motors post-war dream train introduced to the public in 1947.

Previous to his present appointment in 1955, Mr. DeFezzy was supervisor of basic engine design of the Series 51, 71, and 6-110 engines.

Mr. DeFezzy received his degree in mechanical engineering at the Polytechnical Institute in Mittweida, Germany, and attended the university in Dresden, Germany.

Mr. DeFezzy is a member of the Society of Automotive Engineers.

EDWARD R. FRYER,

co-contributor of "Evolution of a Twin Engine, 4-Wheel Drive, Earthmoving Carry-Scraper," is a senior project engineer at Euclid Division. In this capacity he has supervision of carry-scraper and overhung engine tractor design.

Mr. Fryer attended General Motors Institute from 1941 to 1943 as a co-operative student sponsored by Fisher Body Division. From July 1943 to March 1946 he served as an engineering officer with the U. S. Navy. While in service, he attended Massachusetts Institute of Technology under the Navy V-12 program and was graduated in 1945 with the B.S. degree in mechanical engineering. After graduation from M.I.T. he attended Midshipmen's School at Columbia University and Diesel Engineering Officers' School at Cornell University.

Upon separation from the service, Mr. Fryer joined the National Acme Company of Cleveland, Ohio, as a draftsman. In September 1947 he joined Euclid Division as a draftsman-minor layout. He was promoted to draftsman-major layout in 1948. The following year he was promoted to designer. In 1950 he was made product engineer in charge of scrapers. He assumed his present position in 1954.

Mr. Fryer's technical affiliations include membership in the Society of Automotive Engineers. He serves as chairman of this Society's Subcommittee VIII (Cutting Edges) of the Construction and Industrial Machinery Technical Committee.

GEORGE P. HANLEY,

co-contributor of "How a Cutaway Exhibit Was Built to Show the Operation of a 2-Cycle Diesel Engine," is supervisor of basic engine drafting at Detroit Diesel Engine Division.

Mr. Hanley joined Detroit Diesel Engine in 1951 as a design engineer and was promoted to assistant supervisor of basic engine design in March 1955.

He assumed his present duties as supervisor in October 1955.

Mr. Hanley was graduated from the University of Detroit with the bachelor's degree in mechanical engineering in 1942. (In February 1957 he will have completed course work at the University of Detroit required for the master's degree in physics.) Joining the Long Manufacturing Division of Borg-Warner Corporation as a design engineer, he worked on clutches and fluid couplings. In 1946 Mr. Hanley became a member of the faculty of the University of Detroit, College of Engineering. In 1948 he was transferred from the Drawing Department at the University to the Mechanical Department to work on the development of an automotive engineering program.

As a member of the Society of Automotive Engineers, Mr. Hanley co-authored the play "Life in an Engineering Department," which was presented at a meeting of the Detroit Section of the S.A.E. in 1951. He also served on the S.A.E. Faculty Representatives Committee from 1947 through 1951 and contributed the Henry Ford Award Competition paper "Kinematics of Mechanical Planetary Torque Convertors."

Mr. Hanley is a registered mechanical engineer in the State of Michigan.

JOHN L. HARNED,

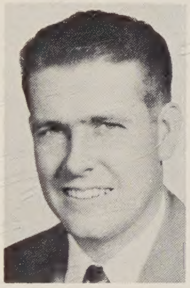
contributor of "Recording Instruments Aid Research Involving Measurement of Dynamic Phenomena," is a research engineer with the Instrument Section of the Technical Facilities and Services Department, GM Research Staff.

The Instrument Section has responsibility for maintaining and servicing all Research Staff instruments and dynamometers. Other services that the section makes available are electronic construction and design, the analog computer laboratory, and instrument application.

Mr. Harned is in charge of the instrument application group which handles the use of instruments in making dynamic measurements. This group sets up complete measuring systems using commercially available transducers, amplifiers, and recorders. Specialized instrumentation systems may have to be developed, also, for specific applications, such as the measurement of high-temperature strain phenomena. In addition, Mr. Harned's group conducts investigations of new measuring techniques, such as the magnetic tape recording technique, for application to industrial research.

The University of Detroit granted Mr. Harned the bachelor's degree in electrical engineering in 1952. Upon graduation, he joined Vickers Incorporated as a test and instrumentation engineer, gaining his early experience in this field. He joined General Motors as a research engineer with the Research Staff in November 1954.

Mr. Harned is a member of Eta Kappa Nu and Tau Beta Pi, honorary societies. His technical society membership includes the American Institute of Electrical Engineers and the Instrument Society of America. He participates on the A.I.E.E.'s membership committee for the Michigan Section and is active on the I.S.A.'s committee on instrumentation for the transportation industry.



FRED L. MAIN,

co-contributor of the problem "Determine the Diameter and Length of a Pin for a Pin-Bushing Type Joint by Bending Stress Evaluation" and the solution appearing in this issue, is supervisor of the Experimental Testing Department of Euclid Division. As supervisor, Mr. Main's work entails responsibility for experimental laboratory testing, such as strain gauge stress analysis, hydraulics, and mechanical testing.

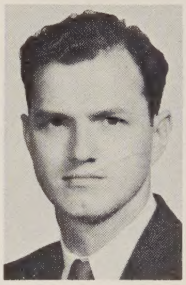
Mr. Main was granted the bachelor's degree in mechanical engineering from Fenn College in 1950 and joined Euclid that year as an engineering trainee in the Product Engineering Department. After completing his training program, he was promoted to design engineer and became project leader for the development of Euclid's experimental, rear-wheel drive, self-propelled scraper and the twin-engine, 4-wheel drive, self-propelled scraper, which were forerunners of Euclid's present line of overhung engine scrapers.

Contributors' backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

When Mr. Main was promoted to test engineer, he was given responsibility for developing and then enlarging the Experimental Testing Department. This assignment included responsibility for the training of other engineers and technicians, purchasing of additional equipment, and setting up of organizational procedures.

Mr. Main received the M.S.M.E. from Case Institute of Technology in 1955. He is a member of Tau Beta Pi, honorary society; the American Society of Mechanical Engineers; and the Society for Experimental Stress Analysis.

From 1943 to 1946 Mr. Main served with the U. S. Army and was awarded the bronze star.



BENJAMIN A. SLUPEK,

co-contributor of the problem "Determine the Diameter and Length of a Pin for a Pin-Bushing Type Joint by Bending Stress Evaluation" and the solution appearing in this issue, is a design engineer in stress analysis at Euclid Division.

Currently he is in charge of the stress analysis group on rubber-tired equipment. The major service functions of this group entail checking new designs for conformance with stress analysis standards and conducting liaison work between engineering design groups and the Metallurgy and Experimental Testing Departments. His previous work has included assistance on structural stress analysis and study of service field problems in the development of overhung engine scraper equipment.

Mr. Slupek joined Euclid in the summer of 1948 as a student trainee in the Industrial Engineering Department. In 1949 he was granted the B.S.I.E. and in 1950 the B.S.M.E. from Pennsylvania State University. Upon graduation he returned to Euclid as a graduate-in-training. From 1950 to 1953 he served as a Lieutenant with the U. S. Air Force, rejoining Euclid in 1953 to work in the Development Engineering Department. He was promoted to design engineer in stress analysis in 1956. At the present time he is completing work for the master of science degree in mechanical engineering at Case Institute of Technology.

Mr. Slupek is a member of Tau Beta Pi, Pi Tau Sigma, Pi Mu Epsilon, and Sigma Phi Sigma, honorary societies, and the Society of Automotive Engineers.

ROBERT H. SPAHR, contributor of "Mobile Laboratory Facilitates Tuning of Automotive Air Intake Silencers," is a project engineer in the Automotive Engineering Department of AC Spark Plug Division.

Mr. Spahr's work entails responsibility for research into the fundamentals of intake silencer operation, development of new types of silencing devices, and investigation into and recommendation on various automotive noise problems. He also is concerned with the development and operation of acoustical test equipment and facilities and is currently working in liaison with the GM Research Staff on an acoustical project being carried on there. One of Mr. Spahr's previous projects occurred during the time of the steel shortage in 1948, when he assisted in the development of an all-aluminum air cleaner and silencer assembly.

Mr. Spahr joined AC Spark Plug as a General Motors Institute co-op student in 1943. He became a junior engineer under the G.M.I. Fifth-Year Program in 1948. After receiving the B.M.E. in 1949 from G.M.I., he became a junior project engineer in the Experimental Engineering Department. He assumed his present position as project engineer in 1951.

Mr. Spahr is a member of Alpha Tau Iota, honorary society. His technical society membership includes the Society of Automotive Engineers and the Acoustical Society of America.

One patent has been issued as the result of his work on air cleaner and silencer design. He is the author of "The Development of an Engine Intake Silencer," which appeared in *Noise Control* for May 1956.

ROBERT L. SPENCER, contributor of "The Engineer in Patent Suits" and this issue's "Notes About Inventions and Inventors," is a patent attorney with the General Motors Central Office Patent Section in Detroit.

Mr. Spencer's work in the Patent Section involves preparation of patent applications for inventions developed by GM employes and the investigation of infringement and validity considerations on new or changed devices or processes used primarily in the field of production relating to automatic transmissions. He also is concerned with patent matters affecting GMC Truck and Coach Division.

Albion College, Albion, Michigan, granted Mr. Spencer the A.B. degree in 1937. The following year he received the B.S. degree in mechanical engineering from the University of Michigan and, continuing his studies in Ann Arbor, was awarded the LL.B. degree in 1941 from the University of Michigan Law School.

Before joining General Motors as a patent attorney in December 1949, Mr. Spencer was employed by the Bendix Aviation Corporation and the Avco Manufacturing Corporation. From 1943 to 1946 he served with the U. S. Navy as a Lieutenant, junior grade. During military service, he was concerned with aircraft maintenance and also patent work at the Radiation Laboratory located at Massachusetts Institute of Technology.

Mr. Spencer is a registered patent attorney and a member of the bar of the State of Michigan.

As a result of his work in the field of refrigeration 1 patent has been granted.

JOHN S. WOLFE, contributor of "How Standards Are Prepared for Stream Pollutant Spectrodetermination," is a chemist with the Engineering Department of Delco Products Division, where he works on special projects and is currently engaged in technical liaison with suppliers of insulating materials. One of his recent special projects has been concerned with stream pollutant analysis, of which he writes. The method developed by Mr. Wolfe has contributed much to stream analysis of the Miami River Watershed.

Mr. Wolfe joined General Motors in 1941 as a junior chemist with Delco Brake Division, which later merged with Moraine Products Division. The next year he transferred to Aeroproducts Operations of Allison Division as a chemist and in 1946 assumed his present position as chemist with Delco Products. This Division produces such items as hydraulic and electric power units, fractional and integral hp motors, automotive shock absorbers, hydraulic cylinders, stand-by generators, fans, and electric controls.

Mr. Wolfe's previous major projects include studies of the deterioration of organic chemical materials, electroplating, emission spectroanalysis, corrosion, adhesion, and hydraulic fluids. The results of his work dealing with various phases of emission spectroanalysis have been published in several papers.

Mr. Wolfe was granted the B.A. degree from The Ohio State University in 1934. His technical society memberships include the American Chemical Society, the Optical Society of America, and the American Association for the Advancement of Science. In addition, he is a member of the Engineers Club of Dayton and the General Motors Spectrographic Committee.

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NGINEERING
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Thermal fatigue and vibration fatigue of turbine buckets are among the foremost problems in the development of new, high-thrust jet engines. In the accompanying photograph, senior research engineer John O. Anderson (foreground) and junior research technician Jackson W. Melichar (background) are shown conducting a study of these problems at the GM Research Staff, General Motors Technical Center.

In a gas turbine engine, the turbine bucket, or blade, becomes extremely hot during engine acceleration and then cools off during constant speed or deceleration periods. This repeated heating and cooling causes thermal fatigue of the metal which shows up as cracks starting from the thin leading edge of a turbine bucket. To pave the way for building aircraft engines of higher efficiency and output, the Research Staff conducted an accelerated test for thermal failures of turbine buckets on a special bench test machine built by the Special Problems Department.

Mr. Anderson is shown monitoring the setup where buckets are held in front of a flame for 20 sec, allowing the leading edge of the bucket to heat to 2,150° F. As the platform revolves, the buckets cool for 1 min to 800° F and are then reheated.

Through this accelerated testing procedure, 32 variations in metallurgy and processing of cast and forged turbine buckets have been evaluated to determine accurately the effects of these variations on the thermal shock resistance of the buckets. This project has added to the understanding of what thermal shock is and how it can be combatted.

Mr. Melichar is shown checking vibration amplitude on a bucket undergoing a high-temperature vibratory fatigue test in another type of machine. Here an air blast excites the heated blade into vibrations of fixed amplitude. Any variation in the frequency of vibration indicates a fatigue failure.

Mr. Anderson's background for this work has been in theoretical and applied mechanics, including evaluation of various high-temperature materials and the development of machines for such evaluation. He also is experienced in vibration studies in strength of materials and general experimental stress analysis. Mr. Anderson was granted the B.S.M.E. from Michigan College of Mining and Technology in 1951 and joined the GM Research Staff as a college graduate-in-training. After working on various assignments in 2 other departments of the Research Staff, he was transferred in 1952 to the Special Problems Department. There he has been advanced from junior engineer to research engineer and, subsequently, to senior research engineer.

Mr. Melichar, a junior research technician, joined the Special Problems Department of the Research Staff in 1953. On-the-job experience has added to his technical training gained through correspondence from the Chicago Technical School.

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